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ERRATA

Page 5, Fig. 1, legend: for 'Wadhurst Clay' read 'Tunbridge Wells Sand'; for 'Tunbridge Wells Sand' read 'Wadhurst Clay'.

Page 143, line 29: for '*Hyposalenia paludensis* Lambert' read '*Goniophorus lorioli* Lambert'.

Page 176, lines 2 and 19: for 'eastwards' read 'westwards'.

Proceedings of the GEOLOGISTS' ASSOCIATION

Subdivision of the Weald Clay in Sussex

by J. W. REEVES

Received 1 October 1957

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ABSTRACT: The monotonous nature and paucity of good exposures have discouraged attempts at subdivision of the Weald Clay in Sussex for more than a century. Using the oldest and youngest of a series of red clay bands occurring throughout the area as Index Horizons, the formation has been divided into three Groups. These are Group I, buff grey, Group II, red, and Group III, yellow. The detailed mapping of the Index Horizons and other beds has produced definite figures for thicknesses of the strata, and shown a very large increase in thickness as the formation is traced to the west and north-west from Eastbourne to Horsham. The Groups are lithological and have not yet been placed in any palaeontological zoning.

1. INTRODUCTION

IT IS, presumably, the outwardly monotonous character of the Weald Clay which has discouraged investigation. cursory examination suggests that it is composed almost entirely of stiff yellow clay. Therefore, since the remarkable piece of pioneer study by Martin (1828), practically nothing except the mapping of its base and top has been attempted on the southern flank. Indeed, but for the search for oil and the actual boring for that valuable raw material on the Pyecombe anticline (51/284128)¹ in 1936, the attention of the writer might not have been directed to any attempt at subdivision. From the general picture of its structure, the Pyecombe anticline

¹ All grid references lie in the 100 km. square 51/—

appeared to have good prospects from an oil company's point of view, except in an area which lay to the north-west of the proposed location (179146) and west of the village of Ashurst (179162). In this area four folds, the Pyecombe anticline, the Henfield (215160) syncline, the Greenhurst (099159) anticline and the Wiggonholt (062168) syncline, operate across an area not more than a mile wide. It was only here that there could be a serious migration of any possible oil to higher structural levels. With this problem of closure in mind, it was suggested that an attempt at six-inch-to-the-mile mapping should be made. Traverses across the main Pyecombe structure showed the possibility of using a vivid red clay as a datum line. The six-inch-to-the-mile mapping which followed, indicated that, over some twenty square miles, satisfactory results could be obtained. A similar bed proved of equal value in the geological interpretation of a smaller area near Pevensey (650050).

2. INDEX HORIZONS

From this mapping and borehole evidence (Reeves, 1948, p. 240) subdivision of the Weald Clay was suggested as follows:

Group III. Yellow. Index Horizon: red clay.

Group II. Variegated. Index Horizon: last strong sandstone.

Group I. Buff grey.

Group I, although mostly exposed as a stiff yellow clay, unvaried and somewhat monotonous, is generally more shaley than the others. Paper shales are found in places. In the north-west of the area it contains many sandstone beds, amongst which the locally famous Horsham Stone occurs. In some places very thin beds of 'catbrain' appear at the base, almost immediately above the Tunbridge Wells Series.

Group II contains all the representatives of a freshwater series: clays, shales, sandstones, sands, ironstones and limestones. The clays and shales occur in many colours, although weathered specimens are mostly yellow. It is this Group which contains some six bands of red clay, scattered at uneven intervals across its thickness.

Group III is even more monotonous and less varied than Group I. It is of yellow clay over large areas with a few impersistent bands of sand, sandstone, ironstone and red clay, the latter very subordinate. In good exposures, e.g. in trenching in the neighbourhood of Codmore Hill (057203), the red clay is seen to be associated with a white clay, but its occurrence is sporadic. In the Cuckmere area (Fig. 1) it occurs as 'cat-brain', a variable stippled admixture of red and white clay. In poor exposures both are shown by a pink coloration on the surface.

Subsequent work has necessitated a modification in this grouping. This lies in the change of the 'Index Horizon' between Groups I and II, pre-

viously given as 'the last strong sandstone' (Reeves, 1948, p. 240) or the Wivelsfield Sandstone (Reeves, 1953, p. 274). It was discovered that the sandstones in the Weald Clay do not make good mapping horizons over long distances (1953, p. 272, footnote). In addition, to the east of the River Adur, and to a larger extent to the east of the River Ouse, sandstones, generally, make but little effect upon the topography, even where they do occur. It is almost impossible to trace a sandstone, or sandy stratum, in areas covered with river terraces of streams whose sources lie in the Tunbridge Wells Sand. These terraces are themselves either sandy or loamy. Further, all through the whole area, there is, as Professor Woolridge pointed out at Fernhurst (1950, p. 169), 'an extensive blanket of redeposited Weald Clay which might well be regarded as a species of loess'.

One such area, near Shortgate (494152), covers at least 125 acres, and is, in places, quite loamy. Finally, in the Cuckmere area no definite sandstone bands occur, although there are thin beds of sand and sandy ironstone.

In face of these practical difficulties, it was decided that 'the last strong sandstone' was neither sufficiently well marked nor consistent enough to be a mappable datum line. Fortunately there was another and a better one. The Oldest Red Clay is just as valuable a marker as the Newest.

The subdivisions suggested in this paper are therefore:

Group III. Yellow. Index Horizon: Newest Red Clay

Group II. Red. Index Horizon: Oldest Red Clay

Group I. Buff grey.

Such a rearrangement will obviously necessitate slight modification of the individual thicknesses given for Groups I and II in previous papers. Some 120 miles of red beds, some forty to fifty miles of sandstone, *Paludina* Limestone and Wealden-Tunbridge Wells boundary were mapped. The mass of local detail collected, therefore, can only be summarised. As, however, the division is based on red clays, a few general remarks on their outcrops should be included.

These red clays, which vary in thickness from a few inches to several feet, stand out prominently against the normal yellow colour of the surrounding clay. They are well shown in ditches, road verges and across newly ploughed fields. This is particularly so in late autumn, winter and early spring when most of this mapping was done. During this time of the year, their outcrops can be 'walked' across ploughed fields, while hedging and ditching operations reveal much that is completely obscured by the dense vegetation of the summer. In pasture-land, or where the 'drift' is thin, the red clays show as a zone of wetter land. Their rubber-like nature in winter and their concrete-like hardness in summer are a bane to the farmer, who will often indicate, somewhat emphatically, their hidden position. While the Newest Red Clay is often three or four feet thick, the Oldest rarely

exceeds one foot. The tracing of it is made relatively easy, since but a few feet above it there lies another red clay which varies in thickness from two to eight feet. Over the whole area both beds have been traced on the six-inch-to-the-mile map, but the outcrop of the former only has been shown on the figures accompanying this paper. These outcrops and excellent exposures in some brickpits—e.g. The Keymer Brickworks, Burgess Hill (323193), where the Oldest Red Clay is well shown—are sufficient almost to trace the red clays through the countryside, but hard bands of sandstone, ironstone and *Paludina* Limestone help where interpolation may be necessary owing to the paucity of red clay exposures. A word of caution must be given. There has been much tipping of red clay along road verges. It has been used as a 'puddle clay' in the building of new stream-road bridges. At St. Hugh's Monastery (206207), near Cowfold, new foundations have been dug for cloisters. The excavations were almost entirely of red clay, which the contractors were dumping in every available pond or hollow. Such red clay 'exposures' can mean a great waste of time in mapping.

This detailed mapping on a six-inch-to-the-mile scale has led to the discovery of many faults and folds hitherto unrecorded. A nomenclature based on place-names which occur on, or near, the flexures on the one-inch-to-the-mile Ordnance Survey maps, has been used. These maps are, Brighton and Worthing Sheet 182 and Eastbourne Sheet 183 (Sixth Edition).

3. DETAILED WORK

For the purpose of description, and also, to some extent upon their geological nature, the region has been divided into four main areas. These coincide, roughly, with the catchment areas of the four larger rivers, the Cuckmere, the Ouse, the Adur and the Arun. As these are not, descriptively, easily defined, the areas have been delineated by the use of the 'eastings' of the National Grid. They are (a) Cuckmere, 480–650, (b) Ouse, 340–480, (c) Adur, 070–340, and (d) Arun, 990–070.

(a) The Cuckmere Area

(i) *Stratigraphy.* Beds of the Wadhurst Clay, the Tunbridge Wells Sand and all Groups of the Weald Clay have been mapped in the area (Fig. 1). The upper beds of the Wadhurst Clay are well exposed about one mile west of Pevensey Church (648048). They are of red clay underlain by grey silts and were shown in trenching operations. The Tunbridge Wells Sand is represented by two small inliers, one near Hankham (619057) and the other just south of Hailsham. Two small sandpits at Lusteds (614064) and Sandbanks Cemetery (585084) show massive, yellow, ferruginous and fine-grained sandstone.

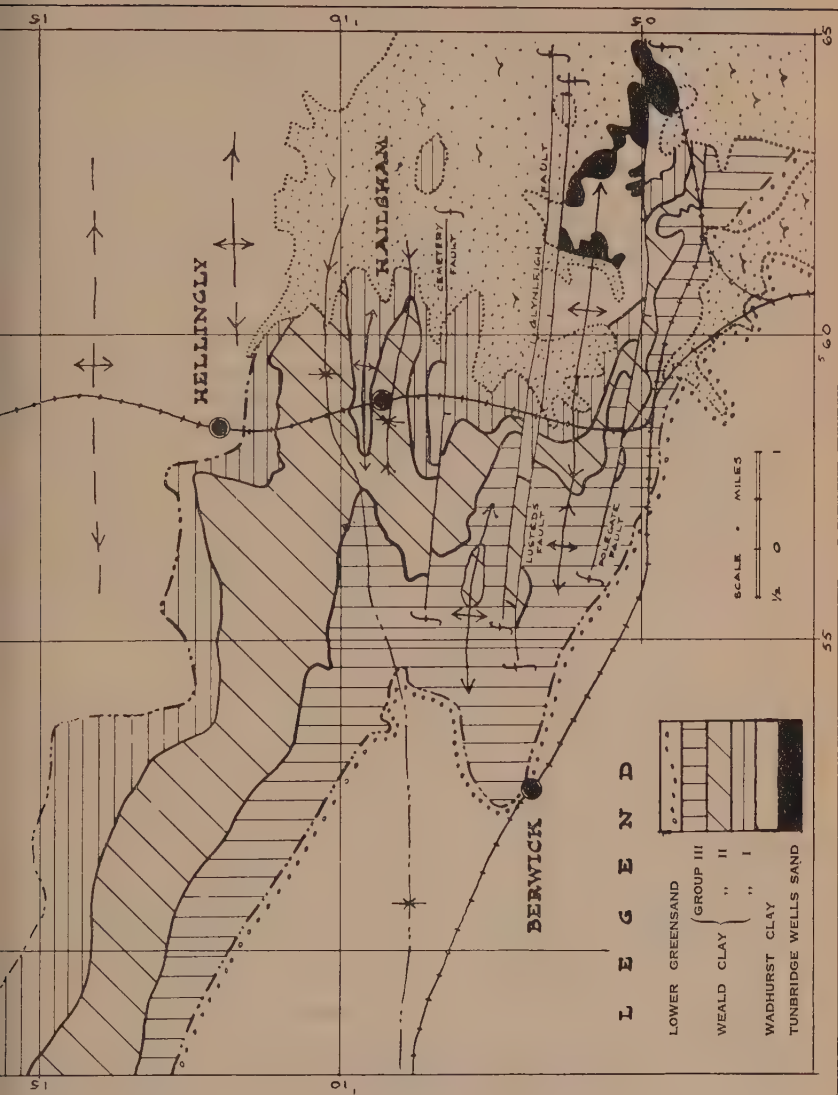


Fig. 1
Weald Clay in the
Cuckmere Area

Group I, Weald Clay, is well shown in a number of brickpits, although most of these are now unused. Hailsham Brickworks (591087) and Coldthorn Brickworks (584080) both expose heavy blue clay with thin beds of sandy ironstone towards the top. These sandy ferruginous beds can be traced over much of the area. They support a 'sandy' flora of bracken, gorse, fir and, occasionally, holly. Occurring, as they do, only a few feet below the Oldest Red Clay, they were useful for interpolation purposes. At Rucklands Brickworks (592112) there are varied grey shales, clays and ironstones. One light purple shale contains ostracods.

The thickness of the Group appears to be fairly constant over the Pevensey-Hailsham area, but begins to expand to the north-west of the latter town.

The Red Group II emerges from below the recent material of the Pevensey Marshes, at (632038). Almost immediately it is exposed in its entirety in the railway cutting at (620040). The exposure shows alternate red and yellow clays, the former predominating. An outcrop near the windmill (620043) just north of the railway line, and another in the road B.2104, show the dip to be four degrees S.53°W. This gives a thickness of fifty feet. At Eastbourne gasworks (623010) a boring for water (Edmunds, 1928, p. 92) shows thirty-eight feet of 'Mottled Clays' at a depth of 378 to 416 feet. This, almost certainly, correlates with the alternating red and yellow clays of the cutting. Excavations in the Stone Cross (615045)-Polegate (586049) road, made the tracing of the Newest Red Clay fairly easy. So did those in Hailsham Road (580053), Polegate. Exposures are good along the road A.22, and in fields either side as far as Hailsham.

In the Southdown Tileries (583068) the upper beds are well exposed in the west of the pit, and the Oldest Red Clay near a small pool to the east. In the pit, the shales and clays are of colours varying from light grey to chocolate and are so disturbed that no true dip could be obtained. At this point the Group is still fifty feet thick, but as it is traced from the pit to the north, it begins to thicken rapidly. This is because of the increased thickness of the yellow (grey where unweathered) clays and shales which alternate with the red clay bands, not by the thickening of the red clay bands themselves. Deep brown silty clays, ironstones and siltstones occur. One of these, near the base of the Group, showed detached tooth crowns, vertebrae and shagreen scales of the fish *Hybodus* probably *basanus* Egerton. Outcrops of red clay in the wooded country to the west of the road A.22 are numerous, as they are on the Hailsham-Upper Dicker (551098) road. An excellent exposure of the Newest Red Clay was seen in the stream course near Milton Hide (561087). In the flatter country to the north-west of Hailsham, although there is some drift material, there are sufficient exposures to outline the outcrop of the Red Clays. Pits in this area have already been described in the Memoir on the Country around Lewes

(Osborne White, 1926). The Memoir also mentions outcrops of *Paludina* Limestone near another Stone Cross (512127). The Association has visited, at least on two occasions, the brickworks near Berwick Station (525070) (Bull, 1936; Higginbottom, 1950), which show the junction of the Weald Clay with the Lower Greensand, and typical beds of Group III, Weald Clay. From samples obtained from disused brickworks near Hackhurst Farm (561123) in Group II, Dr. F. W. Anderson has identified the following ostracods: *Cypridea tuberculata*; *C. valdensis*; *C. springera* and *Darwinula oblonga*. Sandstones outcrop to the north of Laughton Lodge (495133). They are strong enough to be mappable over a short distance. They correlate with those shown to occur in a boring for water at Laughton Lodge itself. One, in Group II, was penetrated by the drill at a depth of sixty-nine to seventy-seven feet, and the other, in Group I, at 277 to 290 feet. These outcrops and well-samples establish the dip in this area, and so the thickness of the Groups. These thicknesses show a very marked increase as the beds are traced to the north-west. This is particularly so in Group II.

	Pevensay	Hailsham	Laughton
	feet	feet	feet
Group III	80	140	140
Group II	50	170	250
Group I	100	100	210
Total	230	410	600

(ii) *Folds and Faults*. As the directions of all fold axes and fault lines, as well as that of the downthrow of the latter, are shown (Fig. 1), it is only necessary to give some account of their size.

The most southerly of the faults is the Polegate (580050). At the point of its emergence from the recent material of the Pevensay Marshes, beds of Wadhurst Clay are faulted against each other. The throw, therefore, may well be less than fifty feet. As the fault is traced westwards, this throw increases, until, with the topmost beds of the Tunbridge Wells Sand on the north, and the middle beds of Weald Clay Group II on the south, the downthrow to the south is about 120 feet. This is at (607049). To the west of this the throw decreases and its effect has ceased before the outcrop of the Lower Greensand has been reached.

To the north lies the Hankham anticline, shown in figs. 3 and 4 of a previous paper (Reeves, 1948). Subsequent mapping of the 'catbrain' band (p. 2) has shown that there is a small saddle at (574062) and a minor crest about (565064).

Exposures of the 'catbrain' and the Newest Red Clay in small inliers show the direction of the first of the two parallel faults, the Lusteds

(614064). Near 'The Lusteds', upper beds of the Wadhurst Clay on the south are faulted against the upper beds of the Tunbridge Wells Sand on the north, giving a downthrow of some eighty to ninety feet north.

The second parallel fault, in the same immediate area, the Glynleigh (604067) fault, the Tunbridge Wells Sands are faulted against beds of the Weald Clay, Group I. Some eighty feet of these were recorded in a shallow borehole near Rickney (626070), which was drilled about 700 feet north of the fault line. In this fault, too, the downthrow is to the north, and its amount about eighty to ninety feet. This throw decreases to the west. The fault passes through the pit of the Southdown Tileries (583068) where dips of eight degrees SE. are noted on its southern side. With beds of Group I to the south and of Group II to the north, the downthrow may be as much as fifty feet. As the rest of the area between the two faults is deeply wooded on the west and covered with a great deal of drift on the east (the drift material consisting largely of resorted Weald Clay and Tunbridge Wells Sand) what is happening in between the two faults is a matter of conjecture.

North of these parallel faults lies the small pericline of Caneheath, well shown by the outcrops of 'catbrain' and Newest Red Clay. It pitches out to the east at (573074). Reports of the occurrence of red clay in shallow wells to the west near Arlington (543075), and rough sections based on maps accompanying Dr. Kirkaldy's paper (1937, pl. VI, 124), indicate that the axis may continue into the Lower Greensand.

The Cemetery fault brings up an inlier of Tunbridge Wells Sand. Where the outcrop of the Oldest Red Clay impinges upon this, the downthrow must be in the neighbourhood of 120 feet south (580083). As in a number of faults in the Weald Clay in this region, the Cemetery fault may be due to the crushing of an anticline.

The complementary syncline, the Hailsham, is slightly asymmetrical with dips on its southern flank of six degrees north, and on its northern one of three and a half degrees south. It has an amplitude of approximately 100 feet (590092). Immediately to the north of this lies the Marshfoot anticline. It is practically symmetrical, having a dip of three and a half degrees south and three degrees north. It has an amplitude of 120 feet (590097). That this is followed by a rather larger syncline is shown by effects upon the strata. While the Hailsham and the Marshfoot folds have affected the Newest Red Clay outcrop but little, this next fold causes that outcrop to swing to the east to form a salient nearly a mile deep. A similar and parallel salient is noted in the Weald Clay-Lower Greensand boundary. It is true that its amplitude is only the same as that of the Marshfoot anticline, 120 feet (590102), and it dips only three degrees on either flank. It is believed, however, that it is the eastern pitching end of the large Mount Caburn syncline, described by H. J. Osborne White (1926, p. 6). The general line of the axis, and sections based on Dr. Kirkaldy's maps (1937), support

the belief expressed above. Northerly salients of Group I outcrop, between Lower Horsebridge (575114) and Hellingly (580123); and between Golden Cross (537125) and Chiddingly (545141) show the pitching ends of anticlines outside the scope of this paper. The first, which could be called the Hellingly anticline, is marked by a tongue of Wadhurst Clay to the east of Carters Corner (608124), as shown on the one-inch-to-the-mile New Series 319. The second, which was tested for oil by the Anglo-American Oil Co. Ltd. in 1937, is the Grove Hill (601140) anticline. Over the rest of the Cuckmere area, the outcrops are unaffected by folds or faults, and follow the general strike of the Cretaceous Beds.

(b) The Ouse Area

(i) *Stratigraphy.* Rocks of the Tunbridge Wells Series and those of Group I, Weald Clay, have been described in a previous paper (Reeves, 1953, p. 269). In Groups III and II there is little change, except for a very gradual introduction of harder beds of sandstone. Outcrops of *Paludina* Limestone were sufficiently numerous to be 'quarried' especially near Plumpton Green (364168). (Fig. 2.) Thicknesses of all Groups, however, have increased considerably. Those at Burgess Hill, where boring for water and good exposures with dip evidence give a well controlled section, have been taken as typical.

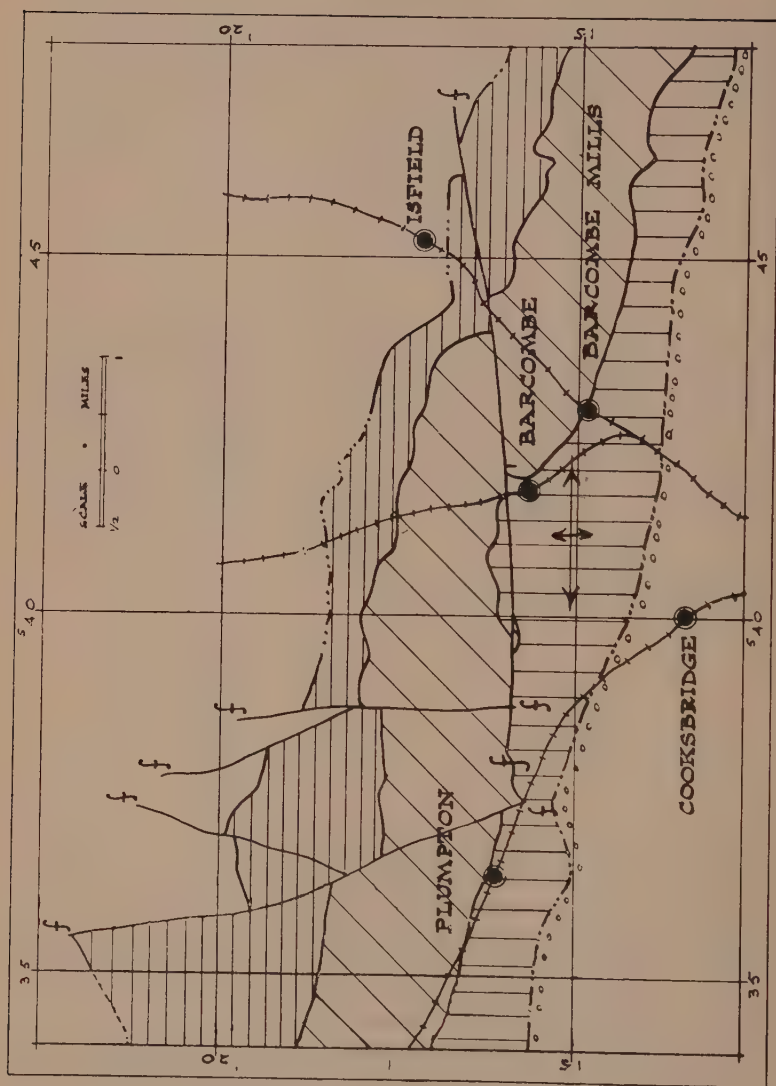
Comparison of these thicknesses yields:

	Pevensey	Laughton	Burgess Hill
	feet	feet	feet
Group III	80	140	230
Group II	50	250	360
Group I	100	210	390
Total	230	600	980

(ii) *Folds and Faults.* This is again a zone of disturbance, but, because of the addition of dip or oblique faulting, it differs from the Cuckmere area.

In the south there is the small pericline of Barcombe Mills, which practically doubles the width of outcrop of Group III. It probably pitches out to the east about (422151) and to the west near (400151). It is so covered with terrace material—loamy beds at least six feet thick in places—that it is difficult to outline the fold with any exactness.

To the north of this small flexure lies the Barcombe Cross (421159) fault, which has, almost certainly, been formed by the axial crushing of another small anticline, starting *en echelon*. A section of this fault was well exposed in a brickyard at (397159). Near Plashnett Park (460167), it has affected the Weald Clay–Tunbridge Wells Sand boundary, moving it some distance to



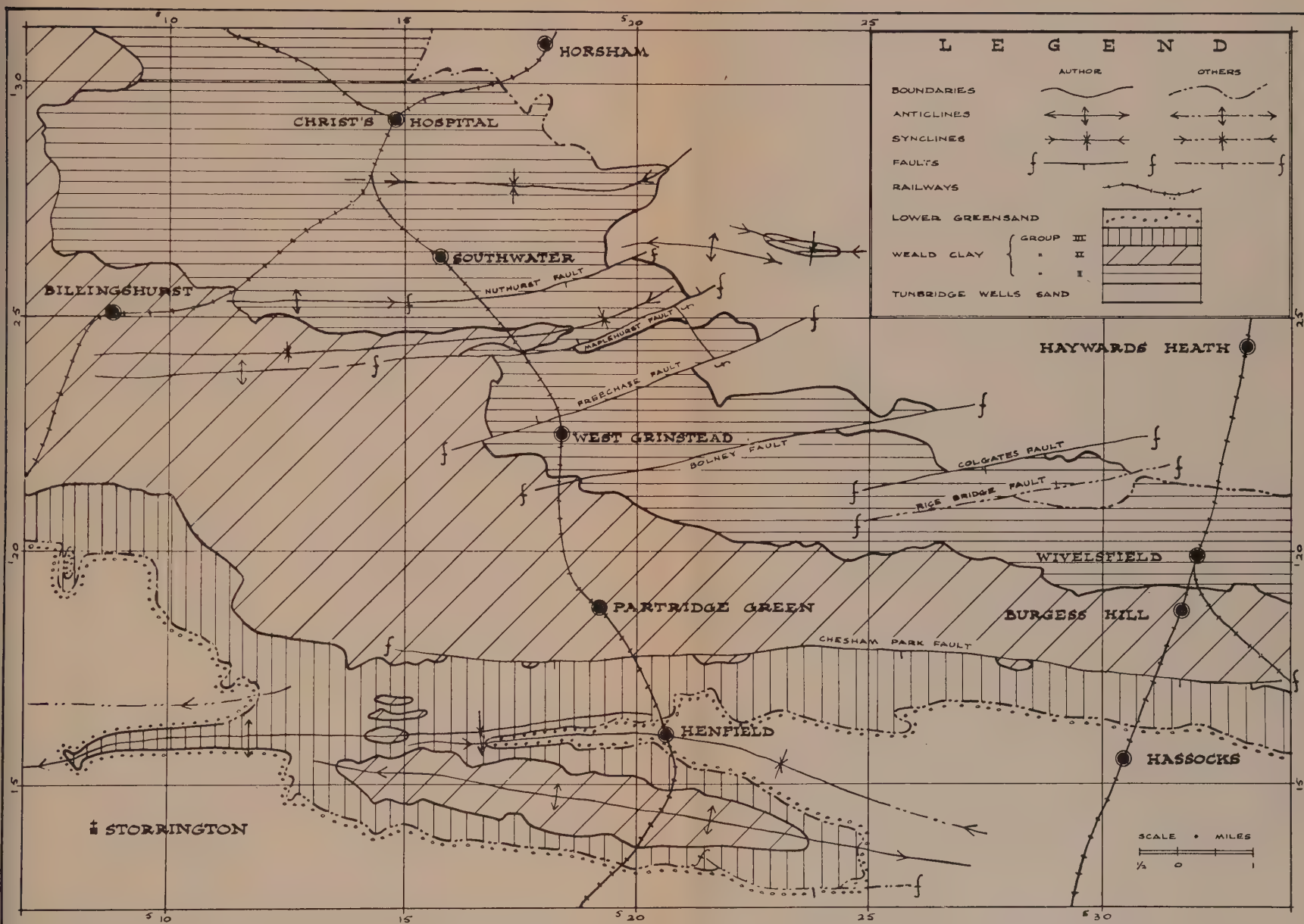


Fig. 3. The Weald Clay of the Adur Area

the east. It has also disturbed the relationship between the Cuckfield (?) Clay and the Upper Tunbridge Wells Sand. At (463167), where the Cuckfield (?) Clay impinges directly upon beds of Group I, the downthrow could easily be as much as ninety feet to the south.

To the west of these strike flexures lies a series of transverse faults, the South Common (390175), the Hooke (383185), the Godleys Green (368198) and the Wivelsfield Green (353200). The last two have already been described (Reeves, 1953, p. 273) and the others exhibit similar, though not quite such violent, characteristics. In the main they tend to widen the outcrop of Group I.

(c) The Adur Area

(i) *Stratigraphy.* Rocks of the Tunbridge Wells Series, consisting at least of the two upper divisions, and all Groups of the Weald Clay, have been mapped in this area (Fig. 3). In the Tunbridge Wells Series, some six bands of clay, alternating with sands and sandstones, have been mapped. Description is, however, being deferred until correlation between these beds and the well-known Cuckfield and Grinstead Clays can be established.

In the Weald Clay, Groups I and II, the main difference between this area and those already described lies in the increasing prominence of sandstones. In Group I it is great enough to allow for some quarrying. This quarrying shows well the variety of the sandstones. Some are of the flagstone type and have been used for roofing, some form blocks for the building of houses and walls, and others are ripple-marked and used in landscape gardening. In places these sandstones, and particularly those with a calcareous cement, have a marked effect upon the scenery. They form low escarpments, which run for some miles across the countryside.

In this lowest Group, too, shales are more conspicuous. Generally the Weald Clay shales tend to weather into a stiff yellow clayey mass, and are not often seen in their true form in minor exposures. In this area, however, they appear to be sufficiently resistant to retain something of their original bedding, in small outcrops in banks, streams and ditches. Paper shales are seen occasionally.

Group II shows some excellent exposures of *Paludina* Limestone. These occur at Henfield Brickworks (218143), where they attain a thickness of nearly twelve inches, and near Coneyhurst Common (105240). Near this hamlet, however, a great deal of this rock has been removed by 'quarrying'.

There has been, once again, an increase in thickness. A well, drilled for water at Billingshurst (084247), penetrated 602 feet of clay, with red clay logged at 195–235 feet; 296–299 feet; 326–327 feet and 374–440 feet (Edmunds, 1928, p. 57). It can be assumed that Group II forms the greater part of the succession, at any rate down to 440 feet. Comparison of thicknesses shows:

	Burgess Hill	Billingshurst
	feet	feet
Group III	230	350
Group II	360	620
Group I	390	400
Total	980	1370

(ii) *Folds and Faults.* The area is readily divisible into two parts, one in the south and one in the north. In both, the general trend of the structures is east-west (Fig. 3).

The southern part has already received a great deal of attention from other workers, Topley (1868, pp. 225-8), Osborne White (1924, p. 6), Kirkaldy (1937, pp. 96-7), The Directors (1947, p. 83) and Reeves (1948, pp. 249-50), but the strike fault forming its northern limit has been newly mapped.

At its western extremity (148178) this Chesham Park (217180) fault is marked with a series of seepages and springs. Its position elsewhere has been fixed by the mapping of small outcrops of the Newest Red Clay, sandy and sandstone beds, and, in the neighbourhood of Burgess Hill, the *Paludina* Limestone. At Brightman's Farm (194179), Reeds Farm (257178) and especially near Franklands Park (316173) where the *Paludina* Limestone impinges directly on to lower beds of Group III, the downthrow to the south must be sixty feet. It is less than this at (176176) at Chesham Park and at (280177), where the Newest Red Clay outcrops to the south of the fault line.

In the northern portion, some of the faults are shown on previously published maps, but have not, as far as the writer is aware, been described. The Rice Bridge (265211) fault and the Colgates (279220) fault affect only the Tunbridge Wells Sand and beds of Group I. The former has a downthrow to the north of some ninety feet, just north of Pains Place (296214) and the latter a downthrow to the south of similar amount near Colgates itself. Thus they largely cancel out each other's effect on the Tunbridge Wells-Weald Clay boundary.

The downthrow of the Bolney fault, which is about fifty feet to the north near the village itself (262226), rapidly increases to the west until at (243226) it is approximately 200 feet. At Well Land Farm (186214), however, its effect has been so much reduced that it only changes the general direction of the outcrop of the Oldest Red Clay.

The effects of the Freechase (239252) fault are somewhat complicated by the presence of the Woldringfold (208246) tear-fault at right angles to it, and within the outcrop of the Weald Clay Group I beds. At a point (212240) where the Tunbridge Wells-Weald Clay boundary impinges directly on to beds high up in Group I, the downthrow to the north must

be in the neighbourhood of 300 feet. To the west of West Grinstead Station, at (166224), it has decreased to some twenty feet. It is suspected from the numerous outcrops of red clay in the neighbourhood of Shipley (145218) that this fault develops into an anticline.

Whether this is true or not, it is certain that the next fault to the north, the Maplehurst (190245), does so. The effects of this fault are, once again, complicated by the Woldringfold tear-fault. Whereas at (210254), to the east of the tear-fault, the downthrow is only some fifty to sixty feet to the north, at (187244), to the west of it, the downthrow has increased to the fairly large amount of 350 feet. Just north of the hamlet Dragon's Green (143235) all faulting has finished, and an anticline has developed. Fortunately a unique opportunity for the study of the folding of this district was given in 1952. The contractors to the North-West Sussex Joint Water Board dug a trench to take the ten-inch water main from the pumping station at Hardham Mill (034178) to Horsham. This trench, running practically at right angles to the strike, showed excellent exposures in many places. In the neighbourhood of Coneyhurst Common (104240), it cut through three outcrops of the *Paludina* Limestone. This bed was hard enough to give good dip readings. South of the hamlet at (100227), the most southerly of the outcrops showed a dip of four and a half to the south. At Balls Green, 2000 feet to the north of the last point, dips on red clay beds and sandstones some inch or so thick show about three degrees, still southerly. In the hamlet itself, at (105243), the dip is one degree north, while 200 feet farther north, and still on the *Paludina* Limestone in the trench, the dip is slightly less than one degree, but to the south. Subsequent mapping of the *Paludina* Limestone showed that the Maplehurst anticline, which had developed from the fault of the same name, was practically a symmetrical one. Near Coneyhurst Common its amplitude, and also that of its complementary Coneyhurst Common syncline, is about sixty feet. To the west, in the neighbourhood of Billingshurst railway station, their amplitudes are nearer 180 feet.

Similar effects, although to a much smaller degree, were noted in the Nuthurst (193262) fault, lying farther north still. While the horizontal displacement of the Tunbridge Wells-Weald Clay boundary is of the nature of 1500 feet to the west, the effect upon a mappable horizon of 'Horsham Stone' at (185258) is approximately 700 feet. The fault, whose greatest downthrow cannot be more than thirty feet, becomes an anticline in Marlpost Wood (150254). This anticline is small, having a slight action only upon the Oldest Red Clay near Duncan's Farm railway bridge (114255) where its amplitude is some ten to fifteen feet.

No trace of the Sedgewick (180270) tear-fault, previously mapped by the Geological Survey on the one-inch-to-the-mile Old Series Sheet 9, could be seen. The disturbance in the area seems to have been caused by a small anticline, the Newells (212266), a neighbouring syncline, the Lower

Beeding (220274) and the Christ's Hospital (148285) syncline, all of which operate in the area north of the Nuthurst fault.

The Newells anticline has an amplitude of less than thirty feet near its crest maximum, while the Lower Beeding syncline is much larger. At its crest minimum at (235266), in beds of Group I, Weald Clay, the amplitude is 210 feet. It is also an asymmetrical fold, for its southern limb dips at four degrees and its northern one more steeply, about eighteen.

The Christ's Hospital syncline, whose eastern pitching end forms a deep salient in the Weald Clay-Tunbridge Wells boundary near Swallowfield (205284), has an amplitude of some 240 feet near the school itself. It is also asymmetrical with a dip of one degree on its southern and a dip of nine degrees on its northern flank.

(d) The Arun Area

(i) *Stratigraphy.* The main work in this area (Fig. 4) lay in the tracing of the Newest Red Clay to link up with the mapping of Professor Wooldridge (1950). It is noted that sandstones play a more, and increasingly, prominent part as the mapping proceeds westwards. In Toat Wood (043216), for

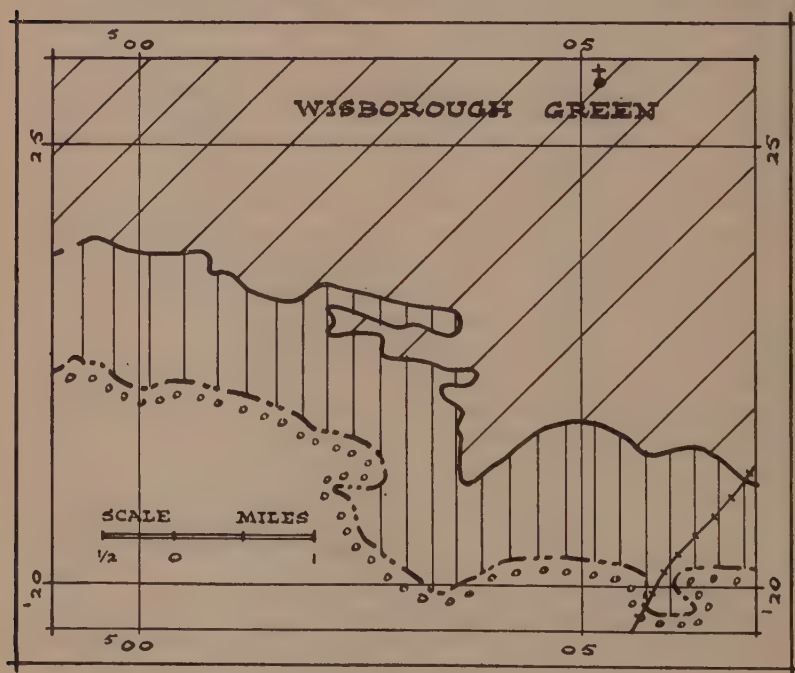


Fig. 4. The Weald Clay of the Arun Area

example, the sandstone underlying the Newest Red Clay has formed small cliffs about five or six feet in height. These beds are thicker than any sandstones seen in Groups III or II to the east.

To the west of the River Arun, one of the 'miniature gorges, for the most part deeply wooded' (Wooldridge, 1950, p. 169) appears, making a long indentation into the outcrop of the Newest Red Clay, which has, hitherto, been fairly even.

(ii) *Folds and Faults.* Except in the case of the Coneyhurst Common syncline (p. 13), whose effect has been lost before its axis line reaches the River Arun, no folds and no faults have been detected in this small area.

CONCLUSIONS

The work has dealt with the subdivision of the Weald Clay on the south crop of the Wealden Anticlinal Structure into three Groups. These are lithological, and depend on the presence, towards the centre of the formation, of a series of red clay bands. The oldest and the newest of these have been used as index horizons, and traced over the whole region. Stratigraphically they are some fifty feet apart in the extreme south-east, but in the extreme west the two beds are separated by some 620 feet of strata. The formation, as a whole, and the other two groups show similar thickening, though not to such a marked degree. The formation increases in thickness six times: Group I, four and a half times; Group II, twelve and a half; and Group III, four times when traced to the west.

Lithologically the formation consists of clays and shales, generally of a yellow or fawn colour when weathered, with subsidiary beds of sand, sandstone, siltstone and limestone. The latter is mostly of the *Paludina* type. The subsidiary beds, however, play an increasingly important rôle as the formation is traced to the west. The mapping has, inevitably, brought to light a number of new folds and faults. Three main areas are noted, in the south-east of 'Cuckmere' (p. 7), in the centre of 'Ouse' (p. 9), and in the south and east of 'Adur' (p. 12). The first and last exhibit mainly the general east and west trend, with folds and faults *en echelon* so common in the Weald. The second area, that of the 'Ouse', shows, however, an anomalous series of north-south tear-faults.

ACKNOWLEDGMENTS

My thanks are due to Dr. J. F. Kirkaldy, for help in the preparation of the text, to Dr. F. W. Anderson for the identification of the ostracods, and to Mr. Mervyn Billingham, who made the tracings from my original drawings.

REFERENCES

- EDMUNDS, F. H. 1928. The Wells and Springs of Sussex. *Mem. geol. Surv. U.K.*
- HIGGINBOTTOM, I. E. 1950. Field Meetings at Lewes, Berwick and Newhaven. *Proc. Geol. Ass., Lond.*, **61**, 300.
- KIRKALDY, J. F. 1937. The Overstep of the Sandgate Beds in the Eastern Weald. *Quart. J. geol. Soc. Lond.*, **93**, 94-126.
- & A. J. BULL. 1936. Report of Field Meeting at Berwick and Hellingly, Sussex. *Proc. Geol. Ass., Lond.*, **57**, 265.
- MARTIN, P. J. 1828. *A Geological Memoir of a part of Western Sussex*. London.
- REEVES, J. W. 1948. Surface Problems in the Search for Oil in Sussex. *Proc. Geol. Ass., Lond.*, **59**, 234-69.
- , 1953. The Wivelsfield Sand. *Proc. Geol. Ass., Lond.*, **64**, 269-75.
- TOPLEY, W. 1875. The Geology of the Weald. *Mem. geol. Surv. U.K.*
- WHITE, H. J. OSBORNE. 1924. The Geology of the Country near Brighton and Worthing. *Mem. geol. Surv. U.K.*
- , 1926. The Geology of the Country near Lewes. *Mem. geol. Surv. U.K.*
- WOOLDRIDGE, S. W. 1950. Some Features in the Structure and the Geomorphology of the Country around Fernhurst, Sussex. *Proc. Geol. Ass., Lond.*, **61**, 165-90.
- THE DIRECTORS. 1947. Whitsun Field Meeting to the Central Weald. *Proc. Geol. Ass., Lond.*, **58**, 73-85.

On the Portlandian Zones of the Vale of Wardour and the use of *Titanites giganteus* as an Upper Jurassic Zone Fossil

by MICHAEL R. HOUSE

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ABSTRACT: The correlation of the Portlandian rocks of the Vale of Wardour with those of the Dorset coast is discussed. It is shown that the holotype of *Titanites giganteus*, commonly used as the uppermost Portlandian zone fossil, comes from the underlying *okusensis* Zone.

1. INTRODUCTION

MUCH WORK is still needed on the stratigraphy of the Portlandian rocks of this country. At this stage only tentative correlations can be made between the Vale of Wardour Portlandian rocks and those of the Dorset coast. The most satisfactory correlation is due to Arkell (1935).

ZONES	ISLE OF PORTLAND	VALE OF WARDOUR
<i>Titanites titan</i>	Freestone Series	? Upper Building Stones
<i>Kerberites okusensis</i>	Cherty Series	Chalky Series
	Basal Shell Bed	Ragstone Beds
<i>Glaucolithites gorei</i>	Portland Clay	
	West Weare Sandstone	Lower Building Stones
	Exogyra Bed	
<i>Zaraiskites alban</i>	Blacknore Series	{ Basement Beds ?

2. THE ZONES OF THE VALE OF WARDOUR PORTLANDIAN

The *alban* Zone has not yet been proved inland. In the Vale of Wardour it may be represented by the lower part of the Basement Beds, i.e. below the Lydite Bed. Here there are no good exposures of these beds at present.

The *gorei* Zone is certainly represented by part, if not all, of the Lower Building Stone Series, in which abundant ammonites with coarse, biplicate ribbing occur as in the West Weare Sandstones. If Buckman (1925) is correct in assigning the holotype of *Kerberites kerberus* Buckman (1925, 5, pl. 520) to Bed 13 of the section described by Miss Benett (in Sowerby, 1818, p. 58) at the Chicks Grove Mill Quarry then the upper part of the Lower Building Stones may belong to the *okusensis* Zone. The series is well exposed in the Chilmark Ravine, Fonthill Lake area, Haselton, Higher Lawn Quarries and at Chicks Grove Mill.

No ammonites have been recorded from the Ragstone Beds which follow the Lower Building Stones. The Ragstone were considered the stratigraphical equivalent of the Basal Shell Bed at Portland by Arkell (1935). The two beds are alike in the excellent preservation of their fossils. A faunal dissimilarity is indicated by the absence from the Portland bed of *Neomiodon cuneatum* (J. Sowerby) which is the most abundant fossil in the ragstones.

As pointed out by Arkell (1933) the Chalky Series seems to represent the *okusensis* Zone.

The Upper Building Stones are represented only in the Chilmark Ravine and have not yielded ammonites. Elsewhere they appear to be cut out by an unconformity at the base of the Purbeck Beds, as at Swindon (Arkell, 1948).

3. THE USE OF *TITANITES GIGANTEUS* AS AN INDEX FOSSIL

There has been much confusion over *Ammonites giganteus* J. Sowerby (1818), generally used as the index species of the highest Portlandian zone. For the following reasons it is recommended that it be replaced as zonal index by *Titanites titan* Buckman, which was preferred by Arkell (1933, p. 481), although he continued to use *giganteus* as second alternative.

The holotype of *Ammonites giganteus* J. Sowerby (1818, p. 55, pl. 126) came from Chicks Grove. In Miss Benett's section of the quarry printed by Sowerby, ammonites are recorded from Beds 6, 10, 11, 12 and 13, but Sowerby stated that his specimen came from the 'Spangle' (Bed 6), the basal member of the Chalky Series. As shown in the table above, this is the equivalent of the lower part of the Cherty Series of Portland, and thus to the Cockly Bed at Swindon, there also the source of giant ammonites.

The commonly repeated error that the type specimen of *Ammonites giganteus* came from the Upper Building Stones horizon in the Thame-Aylesbury district is due to Buckman. In 1921 (3, pl. 256, figs. A, B), he figured as *Gigantites giganteus* a specimen from Long Crendon, near Thame, which he called a 'chorotype', i.e. a specimen from a 'quarry only a short distance away, but in another parish', from a 'stratum lithically the

same as the original locality, with typical examples of named species' (Buckman, 1920, 3, p. 11). This mis-statement misled Arkell (1933, p. 512, and 1947, p. 125) who accordingly stated that the type of *A. giganteus* came from the Thame-Aylesbury district, and it may have influenced Spath (1931, p. 472) in assuming *Gigantites* Buckman (based on *A. giganteus* J. Sowerby) to be a synonym of *Titanites* Buckman (based on the stratigraphically later *T. titan* Buckman from near Thame; 1921, 3, pl. 231). However, both Spath (1936, p. 33) and Arkell (1947a, p. 94) have remarked that the whole of the Portland Stone of Dorset (i.e. *titan* and *okusensis* Zones of the above table) may prove to belong to one ammonite zone when the ammonites have been monographed. In that case '*Titanites giganteus*' would be available for use as the index species.

ACKNOWLEDGMENTS

The writer wishes to thank Dr. W. J. Arkell for helpful discussion during the preparation of this note.

REFERENCES

- ARKELL, W. J. 1933. *The Jurassic System in Great Britain*. Oxford.
 ———. 1935. The Portland Beds of the Dorset Mainland. *Proc. Geol. Ass., Lond.*, **46**, 301–47.
 ———. 1947. *The Geology of Oxford*. Oxford.
 ———. 1947a. The Geology of the Country around Weymouth, Swanage, Corfe and Lulworth. *Mem. geol. Surv. U.K.*
 ———. 1948. A Geological Map of Swindon. *Wiltsh. archaeol. nat. Hist. Mag.*, **52**, 195–212.
 BUCKMAN, S. S. 1909–30. *Yorkshire Type Ammonites*, **1**, **2**, and *Type Ammonites*, **3–7**. Privately published, London.
 SOWERBY, J. 1818. *The Mineral Conchology of Great Britain*. **2**. London.
 SPATH, L. F. 1931. Revision of the Cephalopod fauna of Kachh (Cutch). *Palaeont. indica* (N.S.), **9**.
 ———. 1936. The Upper Jurassic Invertebrate Faunas of Cape Leslie, Milne Land. II, Upper Kimmeridgian and Portlandian. *Medd. om Grönland*, **99**, no. 3.

An Unrecorded Section in the Purbeck of the Vale of Wardour

by S. W. HESTER

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ABSTRACT: A description is given of a temporary section in the Middle and Upper Purbeck near Lower Chicksgrove, Wiltshire, and the fauna of each bed listed. An extension of the outcrop of the Upper Purbeck of the area is inferred.

1. DESCRIPTION OF SECTION

DURING 1937 a cutting excavated for a railway siding leading into the Chilmark Ravine and leaving the main Salisbury to Exeter line three-quarters of a mile east of Lower Chicksgrove exposed a section of the upper part of the Middle Purbeck and the basal Upper Purbeck.

The following is a record of the section:

	ft.	in.
Gravelly clay above		
15. Brown sand with seams of grey laminated clay with <i>Neomiodon</i> sp. ...	3	6
14. Grey clay with thin seams of ferruginous sand ...	1	6
13. Red-brown ferruginous sand ...		2
12. Stiff dark grey and green shell marl, laminated and with beef at the base ...	1	9
11. Grey marly limestone ...		9
10. White buff and dark grey shell marl with thin clay seams and beef. <i>Unio</i> sp., <i>Cypridea fasciculata</i> (Forbes) ...	3	3
9. Fissile grey limestone, blue-hearted and with partings of buff marl. <i>Neomiodon</i> sp., <i>Corbula</i> sp., <i>Macrocypris</i> <i>horatiana</i> Jones & Sherborn, and Cyprid gen. et sp. nov. ...	3	3
8. Buff marl ...	2	6
7. Ferruginous sandy clay ...		4
6. White calcareous shell marl ...		2
5. Brown calcareous shell marl ...		3-6
4. Isopod Limestone. Hard grey marly limestone with thin intercalations of sandy limestone. <i>Archaeoniscus</i> <i>brodiei</i> M. Edwards, <i>Cypridea fasciculata</i> (Forbes), <i>C.</i> <i>propunctata</i> Bradley, <i>Macrocypris horatiana</i> J. and S. <i>M.</i> sp. nov., <i>Viviparus</i> sp. ...		2

	ft.	in.
3. Massive pisolitic blue-hearted sandy limestone, fissile at the top with <i>Neomiodon medius</i> (J. de C. Sowerby), <i>Ostrea cf. distorta</i> J. de C. Sowerby and <i>Cypridea fasciculata</i> (Forbes)	2	6
2. White marl	1	3
1. Cinder Bed. Soft brown rubbly limestone with <i>Laevitrigonia gibbosa</i> (J. Sowerby), <i>Isognomon</i> sp., cf. <i>Hartwellia swindonensis</i> (Blake), <i>Myrene fittoni</i> Casey and <i>Ostrea</i> sp. (base not seen)	1	6 plus

2. DISCUSSION OF SECTION

In general the succession closely resembles that recorded by Andrews & Jukes-Browne (1894) in the railway cutting exposed a half-mile south of Teffont, though the thicknesses of the individual beds vary characteristically.

The full thickness of the lowest bed (Bed 1) was not determined as it was seen only in a small excavation below line-level. This limestone represents the well-known Cinder Bed horizon, the fauna of which indicates a marine invasion during Middle Purbeck times.

The course of massive bedded limestone (Bed 3), separated from the Cinder Bed by white marl (Bed 2), contains a more brackish water fauna, the undoubted marine lamellibranchs of the lower bed being absent. The zonal ostracod of the Middle Purbeck, *Cypridea fasciculata* (Forbes), is present in this bed.

Immediately above Bed 3 occurs the Isopod Limestone discovered by P. B. Brodie (1845). In addition to the rare *Archaeoniscus brodiei* M. Edwards the fauna of Bed 4 includes both freshwater and marine ostracods. The former are present in the grey marly limestone and the latter occur in the wisps of thin sandy limestone within this bed.

The succeeding marls are made up largely of comminuted shells but the fissile grey limestone (Bed 9), which comes above, contains another assemblage of brackish water lamellibranchs to which *Corbula* is a newcomer. The cyprids *Macrocypris horatiana* Jones & Sherborn and Gen. et sp. nov. are present in this bed. In the overlying shell marls *Unio* sp. has been recognised.

Following the classification established by W. R. Andrews (1881) and adopted by H. Woodward (1895) and C. Reid (1903) the division between the Middle and Upper Purbeck in the section here described would appear to be at the top of the grey marly limestone referred to as Bed 11. This conclusion is supported by the presence in Bed 10 of *Cypridea fasciculata* (Forbes), the characteristic ostracod species of the upper half of the Middle Purbeck. No fossils of zonal value were found above this level.

Assuming this classification of the section to be valid it would appear that the area occupied by Upper Purbeck is greater than that indicated on

the current edition of the one-inch geological map sheet 298 (Salisbury), published 1903 and reprinted 1950.

ACKNOWLEDGMENTS

The ostracods from the section have been examined and identified by Dr. F. W. Anderson. The identifications of the other fossils are by C. P. Chatwin and the writer. The Author is grateful to the Director of the Geological Survey and Museum for permission to publish this paper.

REFERENCES

- ANDREWS, W. R. 1881. Note on the Purbeck Beds of Teffont. *Quart. J. geol. Soc. Lond.*, **37**, 248-53.
——— & A. J. JUKES-BROWNE. 1894. The Purbeck Beds of the Vale of Wardour. *Quart. J. geol. Soc. Lond.*, **50**, 55.
BRODIE, P. B. 1845. *A History of the Fossil Insects in the Secondary Rocks of England*. London.
REID, C. 1903. The Geology of the Country around Salisbury. *Mem. geol. Surv. U.K.*, **27**.
WOODWARD, H. B. 1895. The Jurassic Rocks of Britain. The Middle and Upper Oolitic Rocks of England (Yorkshire excepted). *Mem. geol. Surv. U.K.*, **5**, 273.

The Word 'Palaeontology'— a Correction

by L. R. COX

Received 21 November 1957

IN MY 1955 Presidential Address to the Association (*Proc. Geol. Ass., Lond.*, 67, 209–20) I repeated (p. 213) a statement made on p. 122 of H. B. Woodward's *History of Geology* (London, 1911) that the word 'palaeontology' was introduced by Fischer de Waldheim in 1834. Dr. L. S. Davitashvili, of the Institute of Palaeobiology of the Academy of Sciences of the Georgian S.S.R., Tbilisi, has kindly written pointing out that it had previously been used in 1825 by H. M. D. de Blainville (*Manuel de Malacologie*, Paris), where we find (p. 225) the word 'palaeontologie' introduced with the footnote, 'Il me semble utile de créer un mot composé pour désigner la science qui s'occupe de l'étude des corps organisés fossiles'.

Those interested in pursuing the subject further should consult the following paper, of which Dr. Davitashvili has very kindly sent me a copy:

Давиташвили, Л. Ш. и Химшиашвили, Н. Г., 1956. К истории термина "Палеонтология" и некоторых других названий науки об организмах прошлых геологических времен. *Вопросы Истории Естествознания и Техники*, *Акад. Наук С.С.С.Р.*, 1956, Вып. 2, 176–81.

Davitashvili, L. S. & Khimshiashvili, N. G., 1956.—The history of the term 'palaeontology' and of certain other titles connected with the science of organisms of past geological times. *Voprosy Istorii Estestvoznaniia i Tekhniki*, *Akad. Nauk S.S.S.R.*, 1956, no. 2, 176–81.

Easter Field Meeting in the Settle District

8-11 April 1955

Report by the Directors: M. M. SWEETING and W. W. BLACK

Received 18 September 1957

THE OBJECT of the meeting was to study the general geology and geomorphology of the area and to examine in detail the Carboniferous succession at and near the margin of the Askrigg Block. The Golden Lion Hotel in Settle was the headquarters of the party during the meeting. About thirty members and friends gathered there during the evening of Thursday, 7 April, when, after dinner, the Directors gave a brief outline of the geological succession in the area and the problems of the geology and geomorphology to be studied. During the next four days, though the weather was cool and misty, most of the advertised programme was carried out.

Friday, 8 April

The first day was devoted to the country between Settle and Malham. Walking eastwards up High Hill Lane the position of the South Craven Fault (throwing the sandstones and shales of the Millstone Grit series to the south down against the limestones to the north) was noted and a convenient roadside quarry in the limestones was examined (34/825634). The excellent view along the South Craven Fault to the west and north from Castlebergh and Low High Hill was denied to the party by the mist which persisted for most of the day. Farther east the *Lithostrotion arachnoideum* (S_2) limestones were seen in the quarry just west of Scaleber Bridge (34/840627) and a good fauna collected. Immediately downstream from Scaleber Force a branch of the South Craven Fault was demonstrated. A diversion was then made eastward to School Share (34/845624) where the boulder bed in the Bowland Shales was seen. Returning to Scaleber Beck the reef limestones and interbedded dolomites lying above the *L. arachnoideum* beds were examined in the stream section north of Scaleber Bridge and the typical brachiopod reef fauna collected. East of the stream the overstep of the Bowland Shales across the various members of the limestone succession was demonstrated. Stockdale Lane was then reached and, after the lunch-break, followed to Malham. The overlap of the Bowland Shales and Millstone Grit against the eroded fault scarp of the

Middle Craven Fault could not be satisfactorily shown because of the mist. At Malham Cove, the Middle Craven Fault, which is an intra-Carboniferous feature exhumed by more recent erosion, forms a wall-like cliff nearly 300 feet high. At the foot of this cliff rises the River Aire; spring head sapping, assisted by collapse of the limestone, at the source of the river, has caused a recession of the fault-scarp of about half a mile. The party stopped for a long time at the top of the Cove, where the well-known limestone pavements were examined and much discussion took place concerning the origin of some of their features.

Tea was taken in Malham village and some of the party found time for further examination and collecting on the reef limestones of Cawden (34/905630), others for a flying visit to Gordale Scar before returning by bus through Hellifield to Settle.

Saturday, 9 April

The party walked along the road by Giggleswick Scar, the fault-line scarp of the South Craven Fault, to Blackriggs Quarry (34/794660); here the *Girvanella* Band and associated limestones (Upper D_1) were seen and specimens collected. Returning a short distance along the road, the footpath to Feizor was then taken and the *Orionastraea* Band (D_2) examined at an exposure about 1200 yards south-east of the village (34/798667). Continuing through Feizor, a brief outline of the structure and geomorphology of the area was given from a convenient viewpoint; the position of the North Craven Fault and the basal Carboniferous unconformity to the north of it were pointed out. Wharfe Gill, north of Dam House Bridge, was the next stop and here lunch was combined with fossil collecting from the Ashgillian, the *Phacops elegans* limestone, and the *Cyrtograptus murchisoni* lags (34/780696). After lunch the coach took the party on to Ingleton where the geology of the classic 'waterfalls' tour was seen. Starting in the valley of the River Doe the section showing the North Craven Fault (which here throws the shales and thin limestones of the Conistone Limestone series against D_1 limestones) was seen; then the Ingletonian at Pecca Falls, and the basal Carboniferous unconformity at Thornton Force. The geomorphology of the Ingleton gorges was also discussed, in particular the evidence for the repeated rejuvenation of the Rivers Doe and Greta and the polycyclic nature of the relief of the area; the effects of glaciation as shown by the terminal moraine and post-Glacial gorge at Thornton Force were also noted. The normal route of the 'waterfalls' tour was then followed back to Ingleton with a short stop to view the salient features of Mealbank Quarry (34/698736) in the D_1 Limestones between the North and South Craven Faults. After tea in Ingleton the party returned to Settle by coach.

Sunday, 10 April

The coach left Settle for Clapham. From here the party walked up through the grounds of Ingleborough Hall alongside the deeply incised Clapham Beck. The party halted at Ingleborough Cave, near Clapham Beck Head. It had been arranged with the guide for the party to be conducted through the cave, which is one of the best examples of an enlarged bedding-plane cave in north-west Yorkshire. The walk was then continued up Trow Gill and on to the moors on the slopes of Ingleborough. A lunch stop was made at Gaping Gill, one of the deepest and most impressive of the chasm-like pot-holes in the Carboniferous Limestone.

After lunch, the mist became so thick as to make anything but fossil collecting pointless; therefore the remainder of the excursion up Ingleborough was abandoned and the party groped its way to Sulber Gates (34/77732) where the extremely fossiliferous *Davidsonina septosa* beds yielded the usual large fauna. After this the coach was rejoined at Austwick and so back to Settle.

Monday, 11 April

The main object of the programme on the Monday was to study some of the geomorphological problems of the Askrigg Block. The coach took the party first into the upper part of Ribblesdale where the first stop was made at Selside; here the well-known pot-hole of Alum Pot was visited. The party then took the road over Newby Head into Wensleydale (or Yoredale), where the classical Yoredale country was seen. Between Hawes and Aysgarth many of the effects of glaciation upon the Ure Valley were pointed out. Lunch was taken near Aysgarth Falls. From a vantage-point nearby (44/006879), the summit peneplain of this part of the Pennines was well seen. It was then shown how recent mapping of the erosion surfaces of the Askrigg Block together with an examination of the stream profiles had revealed a flight of five major surfaces (or partial peneplains) at consistent levels below the summit peneplain. These surfaces could be traced throughout the Askrigg Block, declining in height towards the east; they appeared to be an essentially similar series of surfaces to those described by McConnell in the Howgill Fells and in the southern part of the Lake District.

The party then went up Bishopdale and over the Kidstones Pass into the head of Wharfedale. Near Grassington, in full view of the Cracoe knoll reefs, recent work on these very interesting features was discussed. This discussion ended the more formal part of the Field Meeting, and here Dr. F. H. Moore expressed the thanks of the party to the Directors. The party then returned by coach to Settle by way of Gargrave and Hellfield.

REFERENCES

- JARWOOD, E. J. & E. GOODYEAR. 1924. The Lower Carboniferous succession in the Settle District and along the line of the Craven Faults. *Quart. J. geol. Soc. Lond.*, **80**, 184-273.
- HUDSON, R. G. S. 1930. The Carboniferous of the Craven Reef Belt; the Namurian Unconformity at Scaleber, near Settle. *Proc. Geol. Ass., Lond.*, **41**, 290-322.
- . 1944. A pre-Namurian Fault-Scarp at Malham. *Proc. Leeds phil. lit. Soc.*, **4** (3), 226-32.
- KING, W. B. R. 1935. The Upper Wensleydale River System. *Proc. Yorks. geol. (polyt.) Soc.*, **23**, 10.
- & W. H. WILCOCKSON. 1934. The Lower Palaeozoic Rocks of Austwick and Horton in Ribblesdale, Yorkshire. *Quart. J. geol. Soc. Lond.*, **90**, 7-31.
- MCCONNELL, R. B. 1940. The Relic Surfaces of the Howgill Fells. *Proc. Yorks. geol. (polyt.) Soc.*, **24**, 152-64.
- SWEETING, M. M. 1950. Erosion Cycles and Limestone Caverns in the Ingleborough district. *Geogr. J.*, **115**, 63-78.

Whitsun Field Meeting at Aberystwyth

7-11 June 1957

Directors: ALAN WOOD, A. J. SMITH, N. J. PRICE

Report by ALAN WOOD

Received 4 October 1957

THE PARTY OF eighteen members and friends assembled on the evening of the 7th to hear an account of recent work in the area from Professor Alan Wood and Dr. N. J. Price, which was illustrated by coloured lantern slides.

Saturday, 8 June

Cader Idris. The party drove to Llyn Gwernan (23/704159), south-west of Dolgeilly, observing and examining on the way the glacial diversion of the River Leri, overflow channels along the course of the Dyfi, slump beds in the Bala near Tre-Taleisin (22/668940), Borth Bog, the Lyfnant tear-fault, and the glaciated cliffs of Aberdovey in the distance. Near Corris rain became severe; nevertheless the party was able to leave the coach to take pictures of Tal-y-Llyn, to view the crags of the Upper Acid Series, the contrasted scree of the Granophyre above and the rounded slopes of the Mudstones to the west. After arrival at Llyn Gwernan the weather cleared, and the party proceeded towards Cader Idris, turning eastwards from the path about half a mile from the road, to observe the tuffs and lavas of the Lower Acid Group and adinolisation of the associated sediments. Good volcanic bombs were collected. After observing a large dolerite sill, the party then examined the Lower Basic Series west of Llyn-y-Gafr, where the whole range of variation within the series was seen, including vesicular and non-vesicular lavas, thin dolerite dykes, pillow lavas and thin bands of shaly sediment. At the moraine-dammed lake of Llyn y Gader (23/708136) the great granophyre sill with giant columns was clearly visible, but the beds above were shrouded in cloud. Here the party separated, one group keeping to the lower ground, going as far as Llyn Aran (23/734139) and observing excellent glacial features, including the tumultuous granophyre blocks of Cerrig Nimbwl, which Professor Wood suggested might have slid over a stagnant corrie glacier to their present position. The larger group climbed Cader Idris by the Foxes Path,



Photograph by the late John F. Hayward

Tectonic ripples in Aberystwyth Grits

Tectonic ripples on the surface of greywacke beds, plunging parallel to the axis of drag-folds. Half a mile north of the end of the promenade, Aberystwyth

[To face p. 28]

descending by the usual route, past the Upper Basic Series, the Llyn Cau Mudstones and the Upper Acid Series to Minfordd (23/732115), where the other party, refreshed by tea in Dolgelly, awaited them.

Sunday, 9 June

Aberystwyth to Wallog. Walking northwards from Aberystwyth along the beach the party observed the sedimentary and tectonic structures of the typical Aberystwyth Grits. Vortex casts, load casts, groove casts and transverse rippling occur on the underside of beds, casts of organic tracks of various kinds also being seen. Within the beds convolute bedding, lamination and grading were distinguished. The Directors pointed out the three key-beds which had enabled them to correlate across folds and faults as far as Clarach (22/588837). Much discussion was aroused by the net-like mesh of *Palaeodictyon* (*Retiofucus* of Keeping), the general opinion being in favour of an organic origin. The remarkable drag-folds and associated shear structures near Cormorant Rock (Plate 1) were demonstrated by Dr. Price, who showed that two periods of movement must be invoked. A peculiar saddle to the south and recent folding caused by landslipping were also seen. As the party approached Clarach an ash band was pointed out, and the correlation with beds near Gilfach was discussed.

After lunch, the party continued to Wallog (22/590858), observing the correlation by lithological pattern, the complicated tectonics and further sedimentary structures. The fragmented (slump) beds, with vortex casts in their bases, near Clarach, and the associated ripple drift bedding attracted much attention. Theories of the origin of the Sarn were discussed at Wallog, and observations made on the coastal geomorphology. Beyond Wallog, attention was concentrated on the slurried beds here so well displayed, it being pointed out that the slurried portion overlies the greywacke in these northern exposures, while it underlies the greywacke portion in the south. The concept of these two types of density current chasing each other down the slope, and the possibility of a photo-finish in the central region, aroused some amusement.

Monday, 10 June

Aberystwyth to New Quay. The day was devoted to a study of coastal geomorphology and the sedimentation of the southern facies of the Aberystwyth Grits. South of Llanrhystyd (22/527686) the bevel and the two levels of the solifluction terrace below were demonstrated. The party then proceeded to Morfa Mawr (22/503657), and viewed the cliffs of the northern part of the Aberarth section. Here the bevel lies behind the remains of two raised beaches, at about eighty feet and 200 feet, and these, as well as the fossil cliff of the submerged beach, could be clearly seen. The sediments contain a higher proportion of grit, in thicker beds, than at Aberystwyth,

and composite beds with load-casting at the interfaces were commonly seen. Tiny injection dykes within a greywacke bed aroused some discussion. After returning to the coach and reaching the top of the cliff, the party viewed the whole sweep of Cardigan Bay, from Pembrokeshire to Bardsey Island, before proceeding to Cei Bach (22/410598). Here the fossil cliff was excellently displayed; the present sea cliff being merely its stripped equivalent. Prolapsed beds, current bedding within thin greywackes which at Aberystwyth would be merely laminated, and a greywacke 'frozen' in the act of picking up portions of a bed beneath, were striking features of the succession. Some members of the party climbed around the headland of Craig Ddu (22/425607) to examine a washout in the grits, while the remainder with Dr. Price observed the tectonics of this area. The party then proceeded to New Quay, where Neptunian dykes and a possible washout filled with black shales aroused much discussion. The view from New Quay was particularly fine, the whole bevelled coastal platform, with Cader Idris, the Rhinogs, Hebog and Snowdon beyond, standing out brilliantly in the evening sun.

After dinner the party visited the Geological Department at Aberystwyth.

Tuesday, 11 June

Devil's Bridge and Monks Cave. In the morning the party travelled by coach towards Devil's Bridge, stopping at the quarry near Bwlch Farm (22/611796), where Mr. Challinor explained his theory of glacial overturning of the highest beds. The lower beds by the road are upside down, their surfaces showing a variety of marks with which members were growing familiar. Bounce casts were particularly well seen. At Devil's Bridge, and on the road beyond, the probable old course of the Rheidol and the causes of the river capture were discussed. The incised meanders in boulder clay were particularly fine. A further stop was made above Nant-yr-arian (22/718813), where glacial features and the remarkable leets were pointed out. At Aberystwyth, where several members left the party, Dr. John F. Hayward moved a very warm vote of thanks to the Directors and particularly to the Secretary, Dr. A. J. Smith.

Lunch was consumed on the cliffs above Monks Cave (22/555745), and afterwards the cliff was safely descended. Egg Rock, an isolated stack doomed soon to disappear, was duly admired. The party then moved southwards, observing the coincidence of tectonic and sedimentary folds along the same axes a quarter of a mile south of Monks Cave. After passing the base of a macro-graded unit of the series, attention was concentrated on tectonics, it being pointed out how the yielding of the thinner beds had concentrated pressure on the thicker ones, which eventually failed and became overthrust.

Continuing south past a series of impressive cliffs the party reached an unnamed cove on the most deserted part of the coast (22/549731), where colonies of nesting sea-gulls and cormorants were seen. Here large vortex casts and, in particular, remarkable slump masses like immense Swiss rolls caused animated discussion. The return was made by climbing the cliff, ropes having been provided, stakes driven in, and steps cut by the energetic secretary and his assistant.

Field Meeting in the Inlier of Benbow and Guy's Hill, Jamaica

JAMAICA GROUP

25 November 1956

Report by the Directors: L. J. CHUBB and B. V. BAILEY

Received 11 June 1957

FROM KINGSTON the main party drove westwards over the Liguanea alluvial plain to Spanish Town, the old capital of Jamaica, and thence northwards through the magnificent limestone gorge of the Rio Cobre to the interior valley or polje of St. Thomas-in-the-Vale. At Linstead several country members were waiting and the augmented party, numbering twenty-eight members and friends in nine cars, took the Guy's Hill road, running towards the north-east. About four miles beyond Linstead the road leaves the interior valley and again enters upon the White Limestone formation, which dips south, so that the first beds seen near milepost 18 belonged to the Lower Miocene zone of *Amphisorus matleyi* Vaughan. Within the next two miles the whole thickness of the White Limestone was traversed, and near milepost 20, Eocene beds with *Dictyoconus* were seen. The Middle Eocene Yellow Limestone formation which normally underlies the White Limestone is here absent, owing to overlap or faulting.

Beyond this there is a gap of 100 yards with no exposures, and then a purple conglomerate was seen which, while it retains its structure, is so decomposed that both pebbles and matrix may be cut with a knife. Matley (1942) interpreted this as the basal conglomerate of the White Limestone, but more recent work suggests that it is Cretaceous in age, and that the relationship between the Cretaceous and Tertiary is a faulted one.

Beyond this the road passed over a series of Cretaceous andesitic lavas and tuffaceous sediments dipping north, vertically intruded by a variety of igneous masses which are mainly acid and include granites and aplite veins. Barytes was found in thin stringers on the west side of the road near to and beyond milepost 21, in the neighbourhood of Gospel Hall Church. The best veins are two or three inches thick. This area of precipitous topography, traversed by a winding road cut into the steep hill-sides, is known as the Devil's Race Course. The last intrusions were seen near milepost 22.

A quarter-mile farther on a road-cutting showed a thin-bedded conglomerate succeeded by a dark limestone containing lapilli and crowded with small rudists, above which were some highly ferruginous purple to red shales, and two thin limestones separated by calcareous shales. These were

followed by a thick series of purple tuffs which extend to beyond milepost 23. All this series is conformable and dips NNE.

In the Benbow district, a little beyond the Rock Hall road junction, about half a mile beyond milepost 23, the purple beds pass under the Benbow Limestone, which is almost black, compact and bituminous, and is here about 900 feet thick. No fossils have been found in this section; Sawkins (1869) mapped it as Cretaceous, while Matley (1942) regarded it as certainly of Tertiary age. Northwards the Benbow Limestone passes under undoubted Middle Eocene beds, a thick series of tuffs interbedded with limestones and sandy shales of the Yellow Limestone formation, which is well developed on the north side of the inlier. Near the office of the Public Works Department in Guy's Hill village many of the fossils characteristic of this formation were collected, such as *Lucina* sp. and *Terebellum procerum* Merian (*T. subdistortum* Trechmann).

The party proceeded eastwards through Arcadia to Springfield, and thence southward to Seafield, this part of the route being over the Yellow Limestone. At Seafield lunch was taken, and members then walked to the spot where the Geological Survey recently drilled an exploratory borehole to a depth of over 600 feet.

A strong magnetic anomaly had been found, in the course of an airborne magnetometer survey, in a belt running nearly E.-W. north of and parallel to the outcrop of the Benbow Limestone, and the purpose of the hole was to investigate this. Samples of the core were shown to the members. After passing through 105 feet of Eocene limestone the drill penetrated a volcanic tuff very rich in magnetite grains, and similar agglomeratic tuff continued to the bottom of the hole. Throughout its thickness the material is so magnetic that it strongly affects a compass needle, and small chips are easily picked up with a magnet. This tuff overlies the Benbow Limestone.

Proceeding southwards the party soon re-entered the Benbow Inlier, the first exposures seen being the surface outcrops of the rocks penetrated in the borehole. A mile south of Seafield, at Golden Grove, some thin limestones were seen interbedded in the tuff. From near here the well-developed hogback ridge formed by the eastward extension of the Benbow Limestone was seen, and this limestone was examined again at the river fording a quarter-mile farther south and in the fields west of the road, where the dip-slope is well exposed. Here many fossils were found including small rudistes and gastropods such as *Actaeonella* sp. and a large species of *Nerinea*, proving that the Benbow Limestone is Cretaceous in age, as Sawkins believed.

Continuing south-westwards to Phillipsburg the party again traversed the purple tuffs with interbedded limestones which underlie the Benbow Limestone. Thence the route ran WNW. to Johnson Hill, where a thin limestone was seen containing a marl band crowded with a small species of

Nerinea, and other Cretaceous gastropods. Beyond this the outcrop of the Benbow Limestone was again crossed, and again specimens of the large species of *Nerinea* were found both in the uppermost beds of the main limestone, and in a higher thin limestone at Cocking Hill, a quarter-mile farther north.

From this point the party returned to Kingston via Benbow and the Devil's Race Course.

REFERENCES

- MATLEY, C. A. & F. RAW. 1942. A Road Section near Guy's Hill, Jamaica. *Geol. Mag.*, **79**, 241-52.
- SAWKINS, J. G. 1869. Reports on the Geology of Jamaica. *Mem. geol. Surv. U.K.*
- TRECHMANN, C. T. 1942. Metasomatism and Intrusion in Jamaica. *Geol. Mag.*, **79**, 161-78.

Field Meeting on Stony Hill and the Junction Road, Jamaica

JAMAICA GROUP

27 January 1957

Directors: L. J. CHUBB and H. R. VERSEY

Report by L. J. CHUBB

Received 11 June 1957

THE PARTY, consisting of thirty-two members and friends, drove from the meeting-place in Kingston, northwards over the Liguanea plain through Half Way Tree and Constant Spring.

Beyond the latter village at milepost 6 the road rises as it enters upon the hills formed by the Tertiary White Limestone formation. The first stop was at Red Gal Ring, where the succession was studied under the direction of Mr. H. R. Versey; it included the Claremont and Somerset Limestones (Upper Eocene), and the lower part of the Brown's Town Limestone (Lower Oligocene). No macrofossils were found in these beds but many foraminifera were collected, including *Lepidocyclina macdonaldi* Cushman, *Fabularia verseyi* Cole and *Dictyoconus cookei* (Moberg) from the Upper Eocene limestones, and *Lepidocyclina undosa* Cushman and *L. favosa* Cushman from the Brown's Town Limestones.

The party then drove up the steeply rising road to Stony Hill at nine miles from Kingston where the island's main watershed, at 1360 feet elevation, was crossed. On the road descending beyond this point, the so-called 'Junction Road', the Troy Limestones (Middle and Upper Eocene) which underlie the Claremont Limestones, and form the lowest member of the White Limestone formation, were seen in road-cuttings. No fossils were found in these beds, which are locally dolomitised; they are underlain by the basal grit of the White Limestone, which rests upon granodiorite. The Middle Eocene Yellow Limestone is not present here, having been overlapped by the White Limestone.

The road descends over the granodiorite, part of the Above Rocks massif, and joins the Wagwater (Agua Alta) river at Golden Spring, where for about half a mile the river follows the line of the Wagwater Thrust. This brings the Lower Eocene Purple Conglomerate on the north-east against the great granodiorite massif on the south-west. Beyond this point the road and river turn west over the granodiorite, which is deeply weathered, producing a cream-coloured clay soil. The route continues for about four miles

in a north-westerly direction, nearly parallel to the thrust, and then turns northward, crossing it at Hall Green, about fourteen and a half miles from Kingston, and one and a half miles in a direct line north-east of Lawrence Tavern.

Here the section in the river-bed was examined. It shows the complex Wagwater Thrust, with imbricating wedges, lenticles and slices of granodiorite, purple conglomerate and porphyry, generally more or less crushed and in places comminuted to form mylonites. This was first recognised as a thrust by Matley (1929, p. 447), but, as was explained to members, Trechmann believes the contact to be an intrusive one. He wrote (1942, p. 170) 'the granodiorite invades the purple Cretaceous [*sic* Eocene] conglomerate as fingers and wedges for some hundreds of feet. . . . Locally it becomes gneissose and the conglomerate alongside of it is crushed and sheared and shows a flow-like structure, but no other contact effects are observable . . . a tongue invading the conglomerate has been intensely shattered, locally powdered to pseudotachylite, and extensively veined.' The crushing, shearing, shattering and powdering, and the absence of thermal metamorphism are consistent with thrusting but inconsistent with an intrusive contact. Pebbles of granodiorite were found in the conglomerate, proving that the former rock had been intruded, consolidated and laid bare by erosion before the latter rock came into existence. The thrust runs in a nearly straight line for a distance of about thirty miles in a NW.-SE. direction, and it was recalled that good sections of it had been seen in cuttings in the new Jacks Hill road, during the Field Meeting in the Port Royal Mountains on 27 November 1955. These cuttings, which are about nine miles south-east of the Wagwater river section, show Purple Conglomerate brought by the high-angled thrust against granodiorite, but a few miles farther in the same direction the thrust brings the Lower Eocene Carbonaceous Shale against the White Limestone of Dallas Mountain, so here there can be no question of an intrusive junction. Still farther south-east it becomes a coastal fault.

Proceeding northwards the party entered upon the Wagwater Belt, a strip about five or six miles wide between the Wagwater and Yallahs Thrusts. It is composed chiefly of the Richmond Beds (Carbonaceous Shale) and of the Purple Conglomerate, which appear to have the same relationship to the Blue Mountain massif that the Flysch and Wildflysch, which they respectively resemble, have to the Alpine massif. The Newcastle Porphyry and Halberstadt Limestone, which were seen in association with these beds in the Port Royal Mountains, the southern continuation of the Wagwater Belt, have not been found so far north as the Junction Road, which makes an oblique traverse of the Belt.

At about fifteen and a half miles from Kingston a copper showing was seen in a high cutting in Purple Conglomerate on the west side of the road.

It consisted of green malachite and blue azurite and chrysocolla, forming thin veins and coating joint faces.

The next stop was at Castleton Botanical Gardens at nineteen miles, just beyond the junction of the Ginger river with the Wagwater river, where lunch was taken. The gardens are on Purple Conglomerate. Again proceeding northwards, beyond Grandy Hole the party passed a lane leading to the Thomasfield area where formerly gold was found, associated with chalcopyrite and other sulphide minerals. Beyond Ugly river bridge at twenty-three miles the road passes on to the grey shales and sandstones of the Richmond Beds, and many good exposures were seen for nearly six miles. Along this stretch the beds are not much disturbed.

About a mile beyond Chovey, at twenty-eight and a half miles from Kingston, a high road-cutting again showed the Richmond Beds, but here they dip steeply towards the south-west. As usual they consist of an alternation of sandstones and shales showing graded bedding, a study of which proved that near road-level the succession is reversed, and therefore that this is the middle limb of an overfold. Higher up in the cliff the beds were seen to curve over, and dip to the north-east, resuming their normal order. A geological map showed that this is on the direct line of the Yallahs Thrust, which is evidently here replaced by an overfold.

Beyond this point the road enters upon the delta of the Wagwater river, which opens into Annotto Bay on the north coast of the island. The party returned to Kingston by the same route.

REFERENCES

- HOSE, H. R. & H. R. VERSEY. 1956. Palaeontological and Lithological Divisions of the Lower Tertiary Limestones of Jamaica. *Colon. Geol. min. resour.*, **6**, 19-39.
- MATLEY, C. A. 1929. The Basal Complex of Jamaica, with special reference to the Kingston District. *Quart. J. geol. Soc. Lond.*, **85**, 440-92.
- . 1951. *Geology and Physiography of the Kingston District, Jamaica*. Crown Agents for the Colonies.
- TRECHMANN, C. T. 1942. Metasomatism and Intrusion in Jamaica. *Geol. Mag.*, **79**, 161-78.
- . 1948. *The West Indies and the Mountain Uplift Problem. Part II*. West Hartlepool.

Field Meeting at Hayes Common and Round Hill, Jamaica

JAMAICA GROUP

24 March 1957

Report by the Directors: G. C. PRESCOTT and H. R. VERSEY

Received 11 June 1957

NINETEEN MEMBERS and friends travelled by car from Kingston to the Parish of Clarendon on a Field Meeting concerned primarily with hydrogeology. The first stop was at Hayes Common where three irrigation wells recently drilled for the West Indies Sugar Company were visited. The wells, which are all about 150 feet deep, first passed through the alluvial Hayes Gravel and penetrated the underlying Tertiary White Limestone formation where water was struck at eighty-one feet, rising under artesian pressure to sixty-nine feet. When tested the wells yielded a total of 6700 gallons per minute with a drawdown of only five feet, although they are less than fifty feet apart.

The next stop was at an old disused hand-dug well in the grounds of Clifton School, which has recently been equipped with an automatic water-level recorder by the Ground Water Branch of the Geological Survey. The hydrograph of the water-level was shown and compared with hydrographs from other wells. They showed that the water-level has a diurnal fluctuation that can be correlated with changes in barometric pressure, indicating that the water is confined probably by beds of clay or silt, as the aquifer is an alluvial one.

The group next travelled to God's Well, a spectacular sink-hole in the White Limestone north of Round Hill, Clarendon. It is about 150 feet wide, and its depth has never been plumbed but it reaches well below the water table which is some eighty feet below ground-level.

The fourth stop was at the Milk River Bath where a highly mineralised thermal spring flows at the rate of about 500 gallons per minute. Like other Jamaican mineral springs it is believed to be deep-seated and to issue from a major fault. The water, which is reported to be among the most radioactive natural waters in the world, appears to be at least in part of juvenile origin. The spring is considered to have therapeutic value, and has been developed as a spa. The radioactivity of the water was demonstrated by Dr. S. A. Vincenz with a scintillation meter. The flow of the spring, like that of the similar Rockfort Mineral Spring east of Kingston, increased

substantially after the earthquake of 1 March 1957, and in the future, periodic measurements of flow, radioactivity, and chemical composition will be carried out.

The final stop was on the south side of Round Hill where a section of the August Town formation, of Upper Miocene age, was visited. The beds here dip steeply southward and are highly fossiliferous. One layer several feet thick consists almost entirely of an oyster resembling *Ostrea haitiensis* Sowerby. In another bed *Gypsina pilaris* (Brady) was so abundant as to give the rock the appearance of an oolitic limestone.

On the beach below this section are considerable accumulations of black magnetite-ilmenite sand. It is believed that the material originated in the Cretaceous tuffs of the Central Inlier, whence it was transported by the Rio Minho southwards to the sea, was swept along the coast by the prevailing E.-W. current and thrown up on the beach during storms.

The Annual Report of the Council of the Geologists' Association for the Year 1957

THE NUMERICAL STRENGTH of the Association on 31 December 1957 was as follows:

Honorary Members	...	...	19	(19)
Ordinary Members:				
Life Members (compounded)	...		179	(171)
Annual Subscribers	...	...	1699	(1688)
Institutional Members	...	...	53	(55)
			1950	(1933)

(Corresponding figures for 31 December 1956 in brackets)

During the year 138 new members were elected, and the Association lost 128 members through death, resignation and removals under Rule XI for failure to pay subscriptions. Seven members were reinstated.

The list of deceased members is as follows: H. G. F. Barham, A. D. Butterley, R. Campbell, L. W. Collet, Miss M. I. Courtenay, A. G. Davis, A. H. Davison, F. A. Henson, H. A. Lake, A. L. Leach, T. W. Marsh, W. Russell, Canon A. F. Smethurst, L. F. Spath, James Wright. (T. C. F. Hall, F. H. Verrall, A. E. J. Vickers, M. Wyatt, 1956. E. A. Nelmes 1955.)

Obituary Notices are published on pages 63-76.

HOUSE LIST

Mr. C. W. Wright retires as President after two years strenuous work in connection with the affairs of the Association, particularly as Chairman of the Publications and Centenary Committees.

Dr. H. Dighton Thomas retires as Senior Vice-President and Mrs. Evans, Mrs. Harrison and Dr. Gilbert Wilson as ordinary members of the Council.

Thanks are due to these members for valuable services rendered to the Association.

FINANCE

The year has been a difficult one but the deficiency of £476 14s. 4d. is largely due to the success in catching up with arrears of publication. The accounts allow for the two parts of the PROCEEDINGS for 1957 not issued by the end of the year and with careful management it should be possible to keep within the expected income for 1958.¹ Once again the Royal Society has made a grant-in-aid to the Association.

Subscriptions came in better in 1957 than for several years past, and the amount of arrears has been reduced. Another encouraging item is the increase both in number of subscribers and in the amount subscribed to the Illustrations Fund.

¹ A Sub-committee has been set up to keep the financial position constantly under review.

INCOME		£	s.	d.	£	s.	d.
1956	ANNUAL SUBSCRIPTIONS RECEIVABLE:						
£	Received for 1957	...	...	...	1557	0	7
1494	Received for previous years	...	...	...	149	0	0
117	Add Arrears at 31 December 1957	£240	10	0			
150	estimated to realise	...	...	...	125	0	0
1761					1831	0	7
200	Less Arrears at 31 December 1956	£294	0	0	150	0	0
1561	estimated to realise	...	...	...			1681 0 7
	ADMISSION FEES RECEIVABLE:						
72	Received for 1957	...	...	...	66	10	0
1	Received for previous years	...	...	...	-	-	-
73					66	10	0
20	Less Arrears at 31 December 1956	...	...	...	-	-	66 10 0
53							
	POST OFFICE INTEREST	...	...	...			12 3 5
25	PROFIT ON FIELD MEETINGS	...	...	...			6 15 6
1	ROYAL SOCIETY GRANT: 1957	...	...	...			300 0 0
200	PUBLICATIONS SALES	...	...	...			350 6 5
237	TRANSFER FROM ILLUSTRATIONS FUND (Statement 6)	...	...	...			67 18 10
29	DEFICIT FOR YEAR CARRIED DOWN	...	...	...			1100 5 6
356					£3585	0	3
22462							
	BALANCE, 1 January 1957	...	...	...			494 5 1
569	TRANSFER FROM COMPOUNDING FUND (Statement 5)	...	...	...			78 8 4
103	TRANSFER FROM BEQUEST FUND (Statement 3)	...	...	...			50 17 9
178	BALANCE (Overdrawn) per Balance Sheet (Statement 1)	...	...	...			476 14 4
-					£1100	5	6
£850							

1956		1957		1958		1959		1960		1961		1962		1963		1964		1965		1966		1967		1968		1969		1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989		1990		1991		1992		1993		1994		1995		1996		1997		1998		1999		2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		2020		2021		2022		2023		2024		2025		2026		2027		2028		2029		2030		2031		2032		2033		2034		2035		2036		2037		2038		2039		2040		2041		2042		2043		2044		2045		2046		2047		2048		2049		2050		2051		2052		2053		2054		2055		2056		2057		2058		2059		2060		2061		2062		2063		2064		2065		2066		2067		2068		2069		2070		2071		2072		2073		2074		2075		2076		2077		2078		2079		2080		2081		2082		2083		2084		2085		2086		2087		2088		2089		2090		2091		2092		2093		2094		2095		2096		2097		2098		2099		2100		2101		2102		2103		2104		2105		2106		2107		2108		2109		2110		2111		2112		2113		2114		2115		2116		2117		2118		2119		2120		2121		2122		2123		2124		2125		2126		2127		2128		2129		2130		2131		2132		2133		2134		2135		2136		2137		2138		2139		2140		2141		2142		2143		2144		2145		2146		2147		2148		2149		2150		2151		2152		2153		2154		2155		2156		2157		2158		2159		2160		2161		2162		2163		2164		2165		2166		2167		2168		2169		2170		2171		2172		2173		2174		2175		2176		2177		2178		2179		2180		2181		2182		2183		2184		2185		2186		2187		2188		2189		2190		2191		2192		2193		2194		2195		2196		2197		2198		2199		2200		2201		2202		2203		2204		2205		2206		2207		2208		2209		2210		2211		2212		2213		2214		2215		2216		2217		2218		2219		2220		2221		2222		2223		2224		2225		2226		2227		2228		2229		2230		2231		2232		2233		2234		2235		2236		2237		2238		2239		2240		2241		2242		2243		2244		2245		2246		2247		2248		2249		2250		2251		2252		2253		2254		2255		2256		2257		2258		2259		2260		2261		2262		2263		2264		2265		2266		2267		2268		2269		2270		2271		2272		2273		2274		2275		2276		2277		2278		2279		2280		2281		2282		2283		2284		2285		2286		2287		2288		2289		2290		2291		2292		2293		2294		2295		2296		2297		2298		2299		2300		2301		2302		2303		2304		2305		2306		2307		2308		2309		2310		2311		2312		2313		2314		2315		2316		2317		2318		2319		2320		2321		2322		2323		2324		2325		2326		2327		2328		2329		2330		2331		2332		2333		2334		2335		2336		2337		2338		2339		2340		2341		2342		2343		2344		2345		2346		2347		2348		2349		2350		2351		2352		2353		2354		2355		2356		2357		2358		2359		2360		2361		2362		2363		2364		2365		2366		2367		2368		2369		2370		2371		2372		2373		2374		2375		2376		2377		2378		2379		2380		2381		2382		2383		2384		2385		2386		2387		2388		2389		2390		2391		2392		2393		2394		2395		2396		2397		2398		2399		2400		2401		2402		2403		2404		2405		2406		2407		2408		2409		2410		2411		2412		2413		2414		2415		2416		2417		2418		2419		2420		2421		2422		2423		2424		2425		2426		2427		2428		2429		2430		2431		2432		2433		2434		2435		2436		2437		2438		2439		2440		2441		2442		2443		2444		2445		2446		2447		2448		2449		2450		2451		2452		2453		2454		2455		2456		2457		2458		2459		2460		2461		2462		2463		2464		2465		2466		2467		2468		2469		2470		2471		2472		2473		2474		2475		2476		2477		2478		2479		2480		2481		2482		2483		2484		2485		2486		2487		2488		2489		2490		2491		2492		2493		2494		2495		2496		2497		2498		2499		2500		2501		2502		2503		2504		2505		2506		2507		2508		2509		2510		2511		2512		2513		2514		2515		2516		2517		2518		2519		2520		2521		2522		2523		2524		2525		2526		2527		2528		2529		2530		2531		2532		2533		2534		2535		2536		2537		2538		2539		2540		2541		2542		2543		2544		2545		2546		2547		2548		2549		2550		2551		2552		2553		2554		2555		2556		2557		2558		2559		2560		2561		2562		2563		2564		2565		2566		2567		2568		2569		2570		2571		2572		2573		2574		2575		2576		2577		2578		2579		2580		2581		2582		2583		2584		2585		2586		2587		2588		2589		2590		2591		2592		2593		2594		2595		2596		2597		2598		2599		2600		2601		2602		2603		2604		2605		2606		2607		2608		2609		2610		2611		2612		2613		2614		2615		2616		2617		2618		2619		2620		2621		2622		2623		2624		2625		2626		2627		2628		2629		2630		2631		2632		2633		2634		2635		2636		2637		2638		2639		2640		2641		2642		2643		2644		2645		2646		2647		2648		2649		2650		2651		2652		2653		2654		2655		2656		2657		2658		2659		2660		2661		2662		2663		2664		2665		2666		2667		2668		2669		2670		2671		2672		2673		2674		2675		2676		2677		2678		2679		2680		2681		2682		2683		2684		2685		2686		2687		2688		2689		2690		2691		2692		2693		2694		2695		2696		2697		2698		2699		2700		2701		2702		2703		2704		2705		2706		2707		2708		2709		2710		2711		2712		2713		2714		2715		2716		2717		2718		2719		2720		2721		2722		2723		2724		2725		2726		2727		2728		2729		2730		2731		2732		2733		2734		2735		2736		2737		2738		2739		2740		2741		2742		2743		2744		2745		2746		2747		2748		2749		2750		2751		2752		2753		2754		2755		2756		2757		2758		2759		2760		2761		2762		2763		2764		2765		2766		2767		2768		2769		2770		2771		2772		2773		2774		2775		2776		2777		2778		2779		2780		2781		2782		2783		2784		2785		2786		2787		2788		27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FUNDS FOR SPECIAL PURPOSES

BEQUEST FUND		Statement 3	
	£	s.	d.
Transfer to Income and Expenditure Account	...	...	...
	50	17	9
	£50	17	9
Balance, 1 January 1957	...	...	...
Investment Income (Statement 13)	...	...	...
	45	12	5
	£50	17	9

[illegible]

COMPOUNDING FUND			Statement 5		
	Uninvested Capital £ s. d.	Income £ s. d.	Uninvested Capital £ s. d.	Income £ s. d.	
Transfer to Income and Expenditure Account	...	...	...	...	
Balance, 31 December 1957 (per Balance Sheet)	128 0 0	78 8 4	128 0 0	71 10 0	
	£128 0 0	£78 8 4	£128 0 0	£78 8 4	

FUNDS FOR SPECIAL PURPOSES (Continued)

ILLUSTRATIONS FUND			Statement 6	
	£	s. d.		£ s. d.
Transfer to Income and Expenditure Account	...	...	...	5 9 0
	...	...	...	62 9 10
	<u>£67 18 10</u>			<u>£67 18 10</u>
			Investment Income (Statement 13)	
			Donations and Subscriptions	...

INDEXING FUND			Statement 7	
	£	s. d.		£ s. d.
Balance, 31 December 1957 (per Balance Sheet)	...	...	...	12 16 4
	...	...	Balance, 1 January 1957	...
	<u>£12 16 4</u>			<u>£12 16 4</u>

WATTS CHARNWOOD FOREST FUND			Statement 8	
	£	s. d.		£ s. d.
Balance, 31 December 1957 (per Balance Sheet)	...	...	...	157 11 3
	...	...	Sales of Books	...
	...	...	...	27 12 3
	<u>£185 3 6</u>			<u>£185 3 6</u>

TRUST FUNDS

FOULERTON AWARD FUND

Award to Mr. H. E. P. Spencer Balance, 31 December 1957 (per Balance Sheet)	...	...	...	...	...	Balance, 1 January 1957 Investment Income (Statement 13)	Statement 9	
							£	s. d.
	...	...	...	...	...	...	15	2 0
	...	...	...	...	...	...	10	9 7
	...	...	...	...	...	...	<u>£25 11 7</u>	

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND

Award to Mr. H. E. P. Spencer Award to Mr. M. J. Hughes Balance, 31 December 1957 (per Balance Sheet)	...	...	...	...	...	Balance, 1 January 1957 Income Tax Recovered ...	Statement 10	
							£	s. d.
	...	...	...	...	...	...	70	9 6
	...	...	...	...	...	...	2	1 5
	...	...	...	...	...	...	<u>£72 10 11</u>	

HENRY STOPES MEMORIAL FUND

Balance, 31 December 1957 (per Balance Sheet)	...	...	...	...	...	Balance, 1 January 1957 Investment Income (Statement 13)	Statement 11	
							£	s. d.
	...	...	...	...	...	...	45	1 2
	...	...	...	...	...	...	7	19 6
	...	...	...	...	...	...	<u>£53 0 8</u>	

JOHNSTON AND HOWARTH FUND

Balance, 31 December 1957 (per Balance Sheet)	...	...	...	...	...	Balance, 1 January 1957 Investment Income (Statement 13)	Statement 12	
							£	s. d.
	...	...	...	...	...	...	64	18 0
	...	...	...	...	...	...	67	16 2
	...	...	...	...	...	...	<u>£132 14 2</u>	

SCHEDULE OF INVESTMENTS—31 DECEMBER 1957

	AT COST OR VALUE		INVESTMENT					
	WHEN ACQUIRED		INCOME (GROSS)					
	£	s. d.	£	s. d.	£	s. d.	£	s. d.
FUNDS FOR SPECIAL PURPOSES:								
Bequest Fund:								
£143 8 9 3½% War Stock	141	14 0			5	0 6		
£150 0 0 New Zealand 3½% Stock 1960/64	122	5 0			5	5 0		
£85 0 0 3% Defence Bonds	85	0 0			2	11 0		
£200 0 0 3½% Defence Bonds (converted from 3% in January 1955)	200	0 0			7	0 0		
£100 0 0 3% Savings Bonds 1960/70	100	0 0			3	0 0		
£441 5 4 3% British Transport Stock 1978/88	400	0 0			13	4 11		
£224 13 3 4½% British Electricity Stock 1974/79	200	0 0			9	11 0		
	1248 19 0						45 12 5	
Centenary Fund:								
£1000 0 0 4½% Defence Bonds (converted from 3½% in June 1956)		1000 0 0					45 0 0	
Compounding Fund:								
£1217 2 6 Nottingham Corporation 3% Irredeemable Stock	1152	13 2			36	10 2		
£200 0 0 3% Savings Bonds 1955/56	200	0 0			6	0 0		
£170 0 0 3½% War Stock	152	14 5			5	19 0		
£100 0 0 3% Savings Bonds 1965/75	100	0 0			3	0 0		
£300 0 0 3½% Treasury Stock 1977/80	282	2 0			10	10 0		
£224 13 3 4½% British Electricity Stock 1974/79	200	0 0			9	10 10		
	2087 9 7						71 10 0	
Illustrations Fund:								
£21 0 10 Metropolitan Water Board 3% 'B' Stock	20	0 0			12	6		
£113 13 1 4½% British Electricity Stock 1974/79	100	0 0			4	16 6		
	120 0 0						5 9 0	
TRUST FUNDS:								
Foulerton Award Fund:								
£349 7 0 3% British Transport Guaranteed Stock 1978/88		294 11 0					10 9 7	
Henry Stopes Memorial Fund:								
£265 19 2 Government of Newfoundland 3% Stock 1943/63		260 12 9					7 19 6	
Johnston and Howarth Fund:								
£1236 4 6 3½% War Stock	1000	0 0			43	5 4		
£495 0 0 4½% Defence Bonds	495	0 0			12	2 3		
£497 3 5 5% Agricultural Mortgage Corp'n. Debenture Stock 1979/83	495	8 2			12	8 7		
	1990 8 2						67 16 2	
TOTAL INVESTMENTS, per Balance Sheet	£7002 0 6							

MARTIN, FARLOW & CO., Incorporated Accountants.

We have compared these Statements with the books and records presented to us and find them to agree.

We have also verified the Investments and Cash Balances held by the Association at 31 December 1957.

J. PITT, Treasurer
February 1958.

CHAS. F. TOZER }
H. W. BALL } Auditors

REPORT OF THE SESSION 1957

TRUSTEES

The Trustees of the Association were:

Managing: Mr. S. Hazzledine Warren, F.G.S., Dr. W. F. Fleet, M.Sc., A.R.I.C., A.C.P., F.G.S., and Mr. Percy Evans, M.A., F.G.S.

Custodian: The Royal Bank of Scotland, Western Branch.

PUBLICATIONS

Publications Committee. The Committee consisted of the seven officers with Mrs. E. M. Evans and Messrs. H. W. Ball, A. J. Dollar, S. E. Hollingworth, J. Sutton, M. K. Wells and G. Wilson. Mr. G. T. Raine succeeded Dr. A. J. Dollar who resigned from the office of Editor during the year, and Dr. D. V. Ager became Secretary of the Committee in place of Dr. M. K. Wells, who also resigned.

The Committee met on eight occasions and considered twenty-five papers, eighteen of which were recommended to the Council for publication.

Proceedings. The four parts of Volume 67 (for 1956) were published during the year in two double numbers. There were 413 pages (compared with 374 for Volume 66) and sixteen plates. The first two parts of Volume 68 were also published during the year and contained 177 pages and five plates. Advertisements were included for the first time. It is expected that the remaining parts of Volume 68 will be published early in 1958.

MEETINGS

Nine Ordinary Meetings were held at which five papers were read, three papers were taken as read and two lectures given. The President, Mr. C. W. Wright, M.A., F.G.S., took the Chair at all of these meetings.

The thanks of the Association are due to the authors of papers and the lecturers and to the Geological Society for use of its apartments throughout the year.

The names of the 138 members elected in 1957 appeared in Circulars numbered 589-599.

4 *January.* Lecture: 'Outlines of the Geology of the Kariba Area', by Francis Jones, T.D., Ph.D., M.Sc., F.G.S. and D. J. Shearman, B.Sc., F.G.S.

1 *February.* Paper: 'Escarpment Dry Valleys near Pegsdon, Hertfordshire', by B. W. Sparks, B.A. and W. V. Lewis, M.A.

1 *March.* Annual General Meeting.

5 *April.* Papers: 'Some Aspects of the Glacial Deposits of Essex', by K. M. Clayton. 'The Stratigraphy and Structure of the Middleton Tyas-Sleightholme Anticline, North Yorkshire', by A. J. Wells (read in title only).

3 May. Papers: 'The Midlands Earthquake of 1957, 12 February, and its after shock of 1957, 12 February', by A. J. Dollar, B.Sc., Ph.D., A.K.C., F.R.S.E., F.G.S. 'A Clactonian Flint Industry at Little Thurrock, Grays, Essex', by J. Wymer (read in title only).

31 May. Lecture: 'A Geological Tour in North America', by Professor E. Hollingworth, M.A., D.Sc., F.G.S.

5 July. Papers: 'The Structure of Sark, Channel Islands', by John Sutton, B.Sc., Ph.D., A.R.C.S., F.G.S. and Janet Watson, Ph.D. 'Some Aspects of the Glacial and Post-Glacial History of the Lower Goyt Valley, Cheshire', by L. J. Rice (read in title only).

9 November. Annual Reunion.

6 December. Paper: 'The Palaeogeography of the London Clay Sea', by the late A. G. Davis and G. F. Elliott. Read by G. F. Elliott.

The Annual General Meeting was held on 1 March 1957. C. W. Wright, M.A., F.G.S., President, in the Chair.

The Annual Report of the Council (previously circulated) was taken as read. It was moved by Mr. E. E. S. Brown, seconded by Mr. C. H. Thomas, 'That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1956'. The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of Council in accordance with Rule XIII: *President*, C. W. Wright, M.A., F.G.S.; *Vice-Presidents*, H. Dighton Thomas, M.A., Ph.D., F.G.S., A. G. Davis, F.G.S., L. R. Cox, O.B.E., M.A., Sc.D., F.R.S., F.G.S., A. J. Dollar, B.Sc., Ph.D., A.K.C., F.R.S.E., F.G.S., D. Curry, M.A., F.G.S.; *Treasurer*, L. J. Pitt, F.G.S.; *Secretaries*, General—F. H. Moore, B.Sc., Ph.D., F.G.S.; Field Meetings—J. M. Hancock, B.A., F.G.S.; Publications Committee—M. K. Wells, M.Sc., Ph.D., F.G.S.; *Editor*, G. T. Raine, B.Sc., A.M.Inst.Pet., F.G.S.; *Librarian*, R. Bradshaw, M.Sc., F.G.S.; *Twelve other Members of Council*, Gilbert Wilson, Ph.D., M.Sc., D.I.C., F.G.S., Mrs. E. M. Evans, M.Sc., F.G.S., Mrs. J. V. Harrison, M.A., B.Sc., D. V. Ager, B.Sc., Ph.D., D.I.C., F.G.S., S. E. Hollingworth, M.A., D.Sc., F.G.S., J. F. Hayward, M.Sc., Ph.D., F.G.S., H. M. Montford, O.B.E., B.Sc., Isles Strachan, B.Sc., Ph.D., F.G.S., D. F. W. Baden-Powell, M.A., B.Sc., F.G.S., S. W. Hester, F.G.S., W. S.itcher, Ph.D., B.Sc., D.I.C., F.G.S., N. B. Peake, F.G.S.

It was moved by Mr. P. Rhodes, seconded by Mr. F. G. Dimes and duly carried, 'That the best thanks of the Association be given to the Officers, the retiring Members of Council and the Auditors'.

On the nomination of the Council, Charles Montague Heanley, M.B., and V. P. D. Stebbing, J.P., F.S.A., L.R.I.B.A., F.G.S., were elected Honorary Members of the Association.

The Foulerton Award and Certificate were presented to Mr. H. E. P.

Spencer, in recognition of work of merit connected with the Association. The President said:

Mr. Spencer: The strength of the Geologists' Association and, I am sure it is fair to say, of British stratigraphical geology has long lain in the band of geologists who watch carefully and become expert on the rocks of the areas in which they reside and on the contents of those rocks. Many of our members in the provinces have become national and international authorities in their selected branches of geology.

Thus you have become an eminent authority on the Pleistocene of East Anglia and on the osteology of the larger mammals of that period. From the nature of most Pleistocene deposits exposures tend to be fleeting and sections even in the more permanent exposures tend to change rapidly. A consistent story in any area therefore depends on the continuous and meticulous recording of temporary exposures. This task you have discharged with conspicuous ability and success in your part of Suffolk.

Among your more outstanding discoveries I would recall that of the shoreline shingle of the Red Crag sea at Battisford and the important series of interglacial deposits at Bobbitshole.

You have recorded the results of some of your work in local scientific journals and in 1952 you led the Association in the field. We all hope to see further accounts of your discoveries and conclusions, perhaps in the pages of our own PROCEEDINGS. It is therefore with great pleasure and in the lively hope that it will represent an encouragement to further work that, on behalf of the Geologists' Association, I hand you the Foulerton Award.

The President then delivered his address entitled, 'Space, Time and Species'.

It was moved by Mr. R. V. Melville, seconded by Mr. A. C. Gifford, and duly carried, 'That the best thanks of the Association be accorded the President for his address'.

FIELD MEETINGS 1957

The Committee consisted of the seven Officers with Messrs. D. F. W. Baden-Powell, D. Curry, S. W. Hester, J. F. Kirkaldy, H. M. Montford, N. Peake, W. S. Pitcher, D. Shearman and W. E. Smith.

Five demonstrations, one week-end, four whole day and four half-day Field Meetings were held during the year.

Easter and Whitsun Field Meetings were held in the Bristol and Aberystwyth districts respectively.

One Summer Long Field Meeting was held in Austria and a second was held in Ireland as a joint meeting with the British Association (Section C).

The thanks of the Association are due to the Directors, Secretaries and all others who organised and assisted at these meetings.

The following Field Meetings and Demonstrations took place:

25 January. Visit to the Laboratory of the Diamond, Pearl and Precious Stone Trade Section of the London Chamber of Commerce, Hatton Garden, at the invitation of B. W. Anderson, B.Sc., F.G.A.

- 16 *February*. Demonstration of Heteromorphic Ammonites by the President at his home.
- 16 *March*. Visit to the Laboratories of Hunting Aerosurveys Ltd., Hunting Geophysics Ltd., and Hunting Technical Services Ltd.
- 13 *April*. Demonstration of the Courses of Some of London's Buried Rivers. Director, R. E. Butler, B.Sc.
- 19-22 *April*. Easter Field Meeting to study the Lower and Middle Jurassic Rocks of the Bristol District. Director, Dr. D. T. Donovan.
- 4 *May*. Field Meeting at Worm's Heath, Surrey. Director, R. J. Jones, M.A., F.G.S.
- 10-12 *May*. Week-end Field Meeting in the Hindhead Area, Surrey and Hampshire. Director, Dr. F. A. Middlemiss.
- 25 *May*. Field Meeting at Henfield, Sussex. Directors, P. Ballance, J. H. Bateson and Dr. J. F. Kirkaldy.
- 7-11 *June*. Whitsun Field Meeting in the Aberystwyth District. Directors, Professor Alan Wood, Dr. A. J. Smith and Dr. Neville Price.
- 15 *June*. Field Meeting at Farnham and Wrecclesham. Director, R. Casey, F.G.S.
- 15 *June*-2 *July*. Summer Field Meeting in Austria. Organising Director, Dr. A. Rüttner; Directors, Dr. H. Küpper, Dr. R. Grill, Dr. W. Heissel and Dr. S. Prey.
- 23 *June*. Field Meeting to study the Hydrogeology of the Lea Valley. Director, Dr. J. F. Hayward; Co-directors, Dr. J. F. Kirkaldy and G. F. Mugele.
- 14 *July*. Field Meeting to study the Lower Greensand near Maidstone. Director, B. C. Worssam, B.Sc., F.G.S.
- 29 *August*-4 *September*. Summer Field Meeting in Ireland. Directors, Professors W. D. Gill and J. C. Brindley.
- 7 *September*. Field Meeting at Reigate. An introductory meeting for those who had done little or no geology in the field. Director, J. M. Hancock, M.A., Ph.D., F.G.S.
- 22 *September*. Field Meeting to study the Chalk of the Thanet Coast. Director, N. B. Peake, F.G.S.
- 5 *October*. Field Meeting at Welwyn. Directors, Professor S. W. Wooldridge and Dr. E. H. Brown.
- 20 *November*. Demonstration at the Hydraulics Research Station, Howbery Park, Wallingford, by kind invitation of the Director.

NORTH-EAST LANCASHIRE GROUP

Chairman, J. Ranson, A.M.I.Min.E., F.G.S.; Secretary, Mrs. J. F. Ranson, B.A.; Committee, H. E. James, B.A., B.Sc., D. H. Learoyd, B.Sc., F.G.S., N. Thompson, S. Westhead, I. A. Williamson, F.G.S.

During the year seven meetings were held and there were four Field Meetings.

18 *January*. 'The Yorkshire Coast', by E. S. Pilling.

15 *February*. 'The Geology of New Zealand', by H. E. James, B.A., B.Sc.

15 *March*. Chairman's Address: 'Studies in Highland Geology', by J. Ranson, A.M.I.Min.E., F.G.S.

12 *April*. 'About Granites', by I. A. Williamson, F.G.S.

25 *May*. Field Meeting: 'The Permo-Trias of Ribblesdale.' Director, D. H. Learoyd, B.Sc., F.G.S.

1 *June*. Field Meeting: 'Rossendale-Pennine Area.' Director, J. Ranson, A.M.I.Min.E., F.G.S.

22 *June*. Field Meeting: 'The Southport-Liverpool Coast.' Director, H. E. James, B.A., B.Sc.

14 *September*. Field Meeting: 'The Todmorden District.' Director, I. A. Williamson, F.G.S.

18 *October*. The thirty-fourth Annual General Meeting. Résumés of the Field Meetings were given by the various directors.

8 *November*. 'Sicily', by Miss M. Powell, B.A., F.R.G.S.

6 *December*. 'The Isle of Arran', by R. Howard, B.A., F.R.G.S.

Thanks are due to the Blackburn Education Authority and the Governors and Principal of the Technical College for the use of rooms.

MIDLAND GROUP

Chairman, H. Sanders; Secretary, I. Strachan, B.Sc., Ph.D., F.G.S.; Committee, Mrs. H. Bone, H. D. Brook, Dr. J. D. Lawson, Ph.D., F.G.S., Dr. W. Tennent, M.D.

Five indoor meetings and five Field Meetings were held.

26 *January*. Professor F. W. Shotton on 'The International Geological Congress 1956'.

2 *March*. Dr. R. J. Adie on 'The Geology of Graham Land'.

13 *April*. Excursion to Money Lane Gravel Pits. Director, Mr. Barton. At his very kind invitation the members afterwards took tea with Professor L. J. Wills.

10-12 *May*. Week-end visit to Llangollen. Director, Mr. Hardie.

2 *June*. Whole day excursion to Caer Carodoc. Director, Mr. Whitehead.

7 *July*. Whole day excursion to the Wrekin. Director, Dr. Strachan.

21 *September*. Half-day excursion to Berrow Hill. Director, Mr. Lacey.

12 *October*. Address by the Chairman, H. Sanders, on 'The Geology of the Island of Rhum'.

9 *November*. Lecture by Professor F. W. Shotton on 'Some Notes on the Geology of Venezuela and Colombia'.

14 *December*. Exhibition of coloured lantern slides and Christmas Party. Thanks are due to Professor F. W. Shotton for the use of the Geology Department, Birmingham University.

NORTH STAFFORDSHIRE GROUP

Professor F. Wolverson Cope, D.Sc., M.I.Min.E., F.G.S.; Chairman, P. S. Keeling, B.Sc., A.R.S.M., F.G.S.; Deputy Chairman, J. T. Wattison, F.G.S., F.R.E.S.; Secretary, T. S. Purcell, B.Sc., F.G.S.; Treasurer, J. T. Gleaves, M.A.; Field Secretary, T. S. Jones, F.G.S.; Research Secretary, D. O. Thomas, F.G.S.; Committee, R. Clark, B.Sc., C. S. Exley, M.A., D.Phil., F.G.S., A. B. Malkin, B.Sc., J. Myers, B.Sc., F.R.G.S., F.G.S., J. C. Parrack, B.Sc., F.R.G.S., E. A. Watkin.

During the year, Field Meetings to the Carboniferous Limestone of Eglwysey (Director, J. C. Parrack, B.Sc., F.R.G.S.) and Tutbury Gypsum Mines (Director, J. Myers, B.Sc., F.R.G.S., F.G.S.) were unfortunately cancelled, due, respectively, to bus strikes and sudden closure of the mines due to illness. Research on the 'Red Rock Fault' junctions continued. Members saw much further evidence of the increasing number of photographic records of the Group's activities. Records of temporary sections should be sent to the Research Secretary. Special thanks go the ladies, who have arranged refreshments throughout the session, and to Professor Cope, in whose Department at the University College of North Staffordshire the Group have twice been guests this year.

The following meetings and Field Meetings were held:

10 *January*. Professor F. Wolverson Cope, D.Sc., M.I.Min.E., F.G.S. 'Some Problems of the Carboniferous Limestone of North Derbyshire.'

14 *February*. 'Geological Topics' discussion evening. Professor Cope, Messrs. T. S. Jones and G. C. Lowe.

14 *March*. Annual General Meeting. Address by retiring Chairman, J. T. Wattison, F.G.S., F.R.E.S.: 'The Calcareous Sandstone of Crail, Fifeshire.'

28 *April*. Field Meeting to the Silurian of Millichope and Wenlock Edge. Director, J. T. Wattison, F.G.S., F.R.E.S.

9 *May*. Visit to the Geology Department of the University College of North Staffordshire.

26 *May*. Field Meeting to the Igneous Complex of Malverns. Director, P. H. Shelford, B.Sc., F.G.S.

15 *June*. Research Group Meeting to Red Rock Fault outcrop.

13 *July*. Research Group Meeting to Red Rock Fault outcrop.

9 *September*. Field Meeting to the Lias and Jurassic Rocks of the Oxford area. Director, T. S. Jones, F.G.S.

10 *October*. The Annual Conversazione, held in the Geology Department of the University College of North Staffordshire.

14 *November*. 'Shaft Sinking', by B. Bentley.

10 *December*. Annual Members' Slide and Photo evening.

JAMAICA GROUP

Chairman, L. J. Chubb, Ph.D., M.Sc., F.G.S.; Vice-Chairman, S. A. G. Taylor; Secretary, E. Robinson, B.Sc.; Treasurer, M. B. C. Scott; Committee, Kathleen O. Cusack, B.Sc., E. L. Frater, B.Sc., H. E. Vendryes, J.P., F.R.M.S., V. A. Zans, F.G.S.

During the year four meetings were held in the Lecture Hall of the Institute of Jamaica, in addition to the Annual General Meeting and Dinner at Manor House Hotel, and there were six Field Meetings. Thanks are due to the Director of the Institute of Jamaica for the use of the Science Library for Committee Meetings.

The following meetings and Field Meetings were held:

25 *January*. Lecture: 'The Age of the Earth', by V. A. Eyles, D.Sc.

27 *January*. Field Meeting: 'Stony Hill and the Junction Road', directed by L. J. Chubb, Ph.D., M.Sc., F.G.S., and H. R. Versey, B.Sc.

24 *March*. Field Meeting: 'Clarendon Plains, God's Well and the Milk River Baths', directed by H. R. Versey, B.Sc., and Glenn C. Prescott, A.B., M.S.

3 *May*. Lecture: 'The Fascinating Search for Oil', by G. K. Serrine, B.S., M.S.

26 *May*. Field Meeting: 'The Palisadoes and Port Royal', directed by V. A. Zans, F.G.S.

5 *July*. Lecture: 'The Pedro Cays', by V. A. Zans, F.G.S.

26 *July*. Lecture: 'Hurricanes', illustrated by the film *Hurricane Watch*, by J. A. Harker, Government Meteorologist.

28 *July*. Field Meeting: 'The Gypsum Deposits of Eastern St. Andrew', directed by V. A. Zans, F.G.S., and R. P. Connett, B.Sc.

29 *September*. Field Meeting: 'The Port Henderson Hills and Green Bay', directed by L. J. Chubb, Ph.D., M.Sc., F.G.S.

24 *November*. Field Meeting: 'The Central Inlier of Jamaica', directed by J. B. Williams, B.Sc.

13 *December*. Annual General Meeting and Dinner.

REUNION

The Annual Reunion was held at the Chelsea College of Science and Technology, 9 November. It was attended by over 300 members and friends.

Thanks are due to the Principal and staff of the College and the members concerned.

LIST OF EXHIBITS

British Museum (Natural History)*Department of Mineralogy*

- (a) Nepheline syenites of the Ilimausak Batholith, Kangerdluarsuk, South Greenland.

Department of Palaeontology

- (b) New discoveries of Pleistocene mammalia, mollusca, and plants from a temporary section in Trafalgar Square and from Willment's gravel pit, Isleworth, Middlesex.

Geological Survey and Museum

- (a) Rock and mineral specimens and geological photographs from Ontario and Quebec.
(b) Other recent acquisitions.
(c) Recent publications.

Ager, Dr. D. V.

- (a) The morphology of the type-species of *Rhynchonella*.
(b) Colour photographs of Turkish geology.

Ainsley, Basil

Some Austrian scenery recorded during the Summer Field Meeting, 1957.

Almy, V. and A. J. Sutcliffe

A new discovery of Pleistocene mammalia at Eastern Torrs Quarry Cave, Yealmpton, near Plymouth.

Bottley, Mr. and Mrs. E. P.

- (a) New radioactive minerals and associated minerals from Borneo, Central Africa and France.
(b) Fine mineral specimens.
(c) A new Hardness Test Scale of exceptional value to Field Mineralogists and Gemmologists.
(d) Devonian slate fossils from West Germany. *Parisocrinus*, *Bactrocrinus*, *Roniaster*, *Aspidodomus*, etc.
(e) Suites of Trilobite casts.
(f) New models of Carboniferous vertebrates.
(g) Photographs of the Dioramas made for County Museums.
(h) Fossil plant slides of Coal Measure plants.

Bowater, Frank A. (Acton County Grammar School)

Exhibition of film-strip record of VI Form field class, Dolgelly-Barmouth area.

Cambridge, Philip

Plio-Pleistocene Fossils of N.W. Europe.

Carreck, J. N., M. P. Kerney and the late A. G. Davis

- (a) Undescribed faunas of the buried channels of the Darent and Medway.

- (b) Non-marine mollusca from an Early Holocene tufaceous loam discovered in the Darent Valley this year.

Carreck, Mrs. M. W. and Mrs. J. V. Fifer (Churchdown County Secondary School for Girls, Bromley, Kent)

A school's introduction to Field work, Isle of Wight, 1957.

Carreck, Mrs. M. W.

The Association's Archives prepared by the late Miss M. S. Johnston and others, with a few recent additions.

Curry, D.

(a) Some microfossils from the London Clay.

(b) *Hystrichosphaeridæ* from the English Eocene.

Cutrock Engineering Co. Ltd.

(a) Laboratory Equipment: Mark I 'Unicutta'—cutting and grinding small cores; Mark II 'Unicutta'—cutting and grinding thin sections; Hydraulic Rock Splitting and Crushing Machine; Mechanical Percussion Mortar; Dr. Dollar's Integrating Micrometer; Croft Grinder; Lakeside 70 Cement; Hotplate; Diamond Wheel Lapping Machine.

(b) Field Equipment: Range of Geological Hammers; Range of Chisels; Dr. Dollar's Pocket Clinometer; Mark II Augers.

(c) Teaching Equipment: Stereometers; Crystal Models; Contact Goniometers.

Dollar, Dr. A. J.

(a) Rocks from the granite laccolith of Scilly.

(b) Preliminary interpretation of a radioactivity survey of Scilly.

Dollar, Dr. A. J. and B. C. Hicks

Demonstration of some applications of a new high temperature microscope furnace in the study of silicates.

Gunner, A.

Chalk Erratics from the Willett Collection, Brighton.

Hancock, Dr. J. M.

Cretaceous Rocks from Austria.

Hayward, Dr. John F.

The Bi-zoned flints of Kent and Essex.

House, M. R., N. E. Butcher and Dr. F. Hodson

Namurian goniatites recently collected from the Upper Culm near Exeter.

Jones, Dr. Francis and Dr. J. Knill

Kodachromes illustrating the Geology of Northern Persia (Iran).

Marston, Alvan T.

(a) Stones in bones: opinions invited.

(b) Varieties in iron-stained flints from the Coombe Rock, Black Rock, Brighton.

Milbourne, R. A.

Albian ammonites from the British Portland Cement Company's clayfield at Small Dole, Sussex.

Owen, H. G.

Ammonites from the Lower Gault and Gault-Lower Greensand Junction.

Raine, G. T. (Editor of the PROCEEDINGS)

The preparation of the PROCEEDINGS of the Geologists' Association.

Ross, F. Stenhouse

Some Inferior Oolite brachiopods and material collected at the Easter Field Meeting, 1957, in the Bristol area.

Smith, W. E.

Projection of colour transparencies of the Cretaceous rocks of South Devon.

Spencer, Harold E. P.

Crag mammalia with special reference to contemporary crag fossils.

Stebbing, Mr. and Mrs. W. P. D.

A small palaeontological collection of various interest from past Field Meetings.

Stinton, Fred C.

Characteristic fossils of the Eocene, Bracklesham Beds.

Whitten, D. G. A., G. T. Raine and Students of the Geology Section, Kingston Technical College

Specimens from the Dartmoor Granite and its Aureole.

Wymer, Mr. and Mrs. B. O. and J. Wymer

Swanscombe Excavations 1957. Some unusual features of the flint industry.

THE LIBRARY

The Library Committee consisted of the President, the Librarian, Mrs. Evans, Messrs. L. R. Cox, M. K. Wells, Gilbert Wilson and J. W. Scott, Librarian of University College, London.

Books and pamphlets presented to the Association are gratefully acknowledged.

The following Institutions have been added to the Exchange List:

Geological Survey of Alsace and Lorraine.

Geological Survey of Nyasaland.

Geological Institute of Warsaw.

Saltykov-Schedrin State Public Library.

University of Lodz.

Martin-Luther University, Halle Wittenberg.

DONATIONS TO THE LIBRARY

- ABHANDLUNGEN ZUR GEOLOGISCHEN SPEZIALKARTE VON ELSASS-LOTHRINGEN. Bd. 2, Heft 2-3; Bd. 3, Heft 1-5; Bd. 4, Heft 1-5; Bd. 5, Heft 2-6. New series, 1-6. 1887-1905.
- ALMEIDA, F. F. M. DE. 1955. Geologia e petrologia do arquipélago de Fernando de Noronha. *Rio de Janeiro*.
- AUSTRIA. *Geologische Bundesanstalt*. [Map.] Die Ostalpen, ihre Ausläufer und Vorlande nebst den angrenzenden Teilen der fränkisch-schwäbischen Alb und des böhmischen Massivs. 1:500,000. 1922-3.
- BLOOMFIELD, K. 1954. The Nachipere series of Southern Nyasaland. *Trans. geol. Soc. S. Afr.*, **67**, 173-93.
- BULLETIN OF THE MYSORE GEOLOGISTS' ASSOCIATION, No. 12-13. 1957.
- CAMBRIDGE, P. G. 1956. Notes on crag palaeontology, 1. *Trans. Suffolk Nat. Soc.*, **9**, 322-7.
- CANADA. *Geological Survey*. Map 55A. Geological map of Alberta, Saskatchewan and Manitoba. 1:2,217,600. 1913.
- . Map 565A. Taber, Alberta. 1:253,440. 1940.
- . Map 566A. Foremost, Alberta. 1:253,440. 1940.
- . Map 567A. Dunmore, Alberta. 1:253,440. 1940.
- . Sections supplementing map 204A. Calgary sheet Alberta. 1928.
- COOPER, C. L. 1946. Pennsylvanian Ostracods of Illinois. *Bull. Ill. geol. Surv.*, 70.
- . 1947. Upper Kinkaid (Mississippian) microfauna from Johnson County, Illinois. *J. Paleont.*, **21**, 81-94.
- COOPER, W. G. G. 1957. The geology and mineral resources of Nyasaland. *Bull. geol. Surv. Nyasaland*, **6**.
- DIXEY, F. 1956. The East African rift system. *Colon. Geol. min. Resour., Suppl. No. 1*.
- EAGAR, R. M. C. 1953. Additions to the non-marine fauna of the lower coal measures of the North Midlands coalfields. *Liv. Manch. Geol. J.*, **1**, 328-69.
- . 1956. New geological displays. *Mus. J. Lond.*, **56**, 109-12.
- EDMONDS, E. A. 1956. The geology of the Bawku-Gambaga area. *Bull. geol. Surv. Gold Cst.*, **19**.
- EIBY, G. A. Earthquakes. *London*.
- FAIRBRIDGE, R. W. 1953. Niveaux multiples de la mer à l'âge post-glacial. *Actes du IV Congrès International du Quaternaire*, 1953.
- . 1954. Quaternary eustatic data for Western Australia and adjacent states. *Proceedings of the Pan Indian Ocean Science Congress*, 1954, 64-84.
- . 1954. Report on limits of the Indian Ocean. *Proceedings of the Pan Indian Ocean Science Congress*, 1954, 18-28.

- FAIRBRIDGE, R. W. 1955. Some bathymetric and geotectonic features of the eastern part of the Indian Ocean. *Deep-sea research*, **2**, 161–71.
- . 1955. Warm marine carbonate environments and dolomitisation. *Tulsa Geographical Society Digest*, **23**, 39–48.
- . 1957. The dolomite question. *Society of Economic Paleontologists and Mineralogists: Regional aspects of carbonate deposition*, 126–78.
- & SERVENTY, V. N. 1954. The archipelago of the Recherche: Physiography. *Australian Geographical Soc. reports No. 1*.
- FLINT, R. F. Glacial and Pleistocene Geology. *New York*.
- FRANCIS, E. H. 1956. The economic geology of the Stirling and Clackmannan coalfield, Scotland, area north of the River Forth. *Coalfield papers of the Geological Survey of Great Britain, No. 1*.
- GARSON, M. S. 1955. Flow phenomena in carbonatites in southern Nyasaland. *Colon. Geol. min. Resour.*, **5**, 311–18.
- GAY, L. O. 1956. Some applications of geophysical methods to geological problems in the Gold Coast. *Bull. geol. Surv. Gold Cst.*, **21**.
- GREAT BRITAIN. *Geological Survey*. Quarter-inch maps.
- Sheet 15. Birmingham, etc. Gravity survey overlay map. 1954.
- Sheet 22. Plymouth, etc. Solid and drift. 1953.
- . 1 inch maps.
- Sheet 70. Leeds. Drift. 1951.
- Sheet 100. Sheffield. Solid and drift. 1956.
- Sheet 157. Stamford. Solid and drift. 1957.
- GREAT BRITAIN. *Geological Survey*. The limestones of Scotland: chemical analyses and petrography. *Special reports on the mineral resources of Great Britain*, **37**. 1956.
- GREAT BRITAIN. Limestone. *Ministry of Housing and Local Government*. [2 maps and explanatory text.] 1955.
- HABGOOD, F. 1956. Report on the recent investigation of the Sumbukombedzi coalfield, Chikawawa district. *Geological Survey Nyasaland, Report No. 1, new series*.
- HALLAM, A. 1955. The palaeontology and stratigraphy of the marlstone rock-bed in Leicestershire. *Trans. Leicester. lit. phil. Soc.*, **49**, 17–35.
- HALLESCHES JAHRBUCH FÜR MITTELDEUTSCHE ERDGESCHICHTE, Bd. 2, Lief. 3, 1956.
- HARRIS, N. 1957. Domestic water supplies in rural areas. *Geological Survey Uganda Water supply paper No. 3*.
- HATUDA, Z., and NISHIMURA, S. 1956. Variation in radioactivity across igneous contacts. *Mem. Coll. Sci. Kyoto, ser. B*, **23**, 285–95.
- HAYASE, I. 1956. The radioactivity of rocks and minerals studied with nuclear emulsion IV. *Mem. Coll. Sci. Kyoto, ser. B*, **23**, 255–74.
- HOLT, D. N. 1955. The location of underground water supplies in Nyasaland. *Colon. Geol. min. Resour.*, **5**, 438–40.

- HORNIBROOK, N. de B. & H. J. HARRINGTON. 1957. The status of the Wangaloan stage. *N.Z. J. Sci. Tech.*, sect. B, **38**, 655-70.
- HUTCHINSON, G. E. A Treatise on Limnology. *New York*.
- ITO, H. 1956. Temperature of granite magma of Kitashirakawa granite, Kyoto, Japan, as estimated from a heat conduction theory of formation of Wollastonite. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 305-23.
- ITOIGAWA, J. 1956. Molluscan fauna of the Tsuzuki group in Kyoto Prefecture, Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 179-92.
- JONGMANS, W. J. 1954. Contribution to the knowledge of the flora of the seam Girondelle (lower part of the Westphalian A). Pt. 1. *Meded. Geol. Sticht.*, serie C, III, **1**, No. 4.
- KANSAS UNIVERSITY. 1956. The Kansas basin: pilot study of a watershed. *Kansas*.
- KEAR, D. 1957. Kauaeranga sulphide deposit, Thames. *N.Z. J. Sci. Tech.*, sect. B, **38**, 483-95.
- & W. P. TOLLEY. 1957. Notes on Pleistocene and Jurassic beds near Morrinsville. *N.Z. J. Sci. Tech.*, sect. B, **38**, 500-6.
- KERNEY, M. P. 1955. On the former occurrence of *Vertigo parcedentata* (A. Braun) in Hertfordshire. *J. Conch.*, **24**, 55-8.
- . 1957. Early post-glacial deposits in King's County, Ireland, and their molluscan fauna. *J. Conch.*, **24**, 156-64.
- KINGMA, J. T. 1957. The North Island geanticline in the Hawke's Bay sector. *N.Z. J. Sci. Tech.*, sect. B, **38**, 497-9.
- KUMAGAI, N. & T. HANAOKA. 1956. A note on reflecting power of rocks. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 275-83.
- LIEBHEIM, E. 1900. Beiträge zur Kenntniss des lothringischen Kohlengebirges. Atlas. *Abh. geol. Specialk. Els.-Loth.*, n.f., Heft 4.
- LUDLOVIAN RESEARCH BULLETIN, No. 4-5. 1956-57. *Birmingham*.
- MAKIYAMA, J. 1956. Cyclic Nepton group of Kinki area, Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 169-77.
- MARWICK, J. 1957. Generic revision of the Turritellidae. *Proc. Malac. Soc.*, **32**, 144-66.
- MITTEILUNGEN DER GEOLOGISCHEN LANDESANSTALT VON ELSASS-LOTHRINGEN, Bd. 1, Heft 1-3; Bd. 3, Heft 1-5; Bd. 5, Heft 1-3, 5; Bd. 6, Heft 2-3; Bd. 7, Heft 1-4; Bd. 8, Heft 1-3; Bd. 9, Heft 1-3; Bd. 10, Heft 1-3; Bd. 11, Heft 1-2; Bd. 12, Heft 1-2. 1888-1918. *Strassburg*.
- MOORE, R. C. 1957. Treatise on invertebrate paleontology. Part L: Mollusca, 4. *New York*.
- MORISHITA, A. 1956. On some fossil echinoids from Kyuyu, Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 193-202.
- MUTCH, A. R. 1957. Facies and thickness of the Upper Paleozoic and Triassic sediments of Southland. *Trans. roy. Soc. N.Z.*, **84**, 499-511.
- NAKAZAWA, K. 1956. A study on the Pelecypod-fauna of the Upper

- Triassic Nabae group in the northern part of Kyoto Prefecture, Japan. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 231-48.
- NORTH, F. J. 1938. Geological maps, their history and development with special reference to Wales. *Cardiff*.
- . 1938. Studies on the origin of the scenery of Wales. 1. The river scenery at the head of the Vale of Neath. *Cardiff*.
- . Sunken cities. *Cardiff*.
- OYEN, F. J. van. 1956. Contribution à la connaissance de genre *Adelophthalmus* Jordan et Meyer 1854. *Meded. Geol. Sticht.*, serie C, IV, **3**, No. 7.
- PALLISTER, J. W. 1956. Slope form and erosion surfaces in Uganda. *Geol. Mag.*, **93**, 465-72.
- PARKINSON, D. 1956. The species concept applied to the study of Carboniferous brachiopods and goniatites. *Systematics Assoc. Publication No.* 2, 117-20.
- . 1957. Lower Carboniferous reefs of northern England. *Bull. Amer. Ass. Petrol. Geol.*, **41**, 511-37.
- PROCEEDINGS OF THE MYSORE GEOLOGISTS' ASSOCIATION, 1955, 1956.
- QUENNELL, A. M. 1956. The Bukoban system of East Africa. *XX Congreso Geologico Internacional: El sistema cambrico*, etc., tom. 1, pt. 1.
- RAST, N. & J. I. PLATT, 1957. Cross folds. *Geol. Mag.*, **94**, 159-67.
- RAW, F. 1956. Origin of winged insects. *Ann. Mag. nat. Hist.*, ser. 12, **9**, 673-85.
- . 1957. Origin of Chelicerates. *J. Paleont.*, **31**, 139-92.
- ROBERTS, G. E. 1860. The rocks of Worcestershire. *London*.
- STEVENS, G. R. 1956. Earth movements in the Wellington area. *N.Z. Geogr.*, **12**, 189-94.
- . 1956. Hutt Valley artesian system. *N.Z. J. Sci. Tech.*, sect. B, **38**, 149-56.
- . 1956. Stratigraphy of the Hutt Valley, New Zealand. *N.Z. J. Sci. Tech.*, sect. B, **38**, 201-35.
- . 1957. Geomorphology of the Hutt Valley, New Zealand. *N.Z. J. Sci. Tech.*, sect. B, **38**, 297-327.
- . 1957. Solifluxion phenomena in the lower Hutt area. *N.Z. J. Sci. Tech.*, sect. B, **38**, 279-96.
- STINTON, F. C. 1957. On the occurrence of Teredinidae in the Upper Eocene of Barton, Hampshire. *Proc. Malac. Soc.*, **32**, 167-73.
- . 1957. Teleostean otoliths from the Tertiary of New Zealand. *Trans. roy. Soc. N.Z.*, **84**, 513-17.
- STRINGER, K. V., D. N. HOLT, etc. 1956. The Chambe plateau ring complex of Nyasaland. *Colon. Geol. min. Resour.*, **6**, 3-18.
- SULLIVAN, H. J. & L. R. MOORE. 1956. The horizon of the Tillery vein in Monmouthshire. *Geol. Mag.*, **93**, 409-17.

TANGANYIKA. *Geological Survey*. Maps, 1:125,000.

Degree sheet 28—Nzega, N.E. quarter. 1956.

Degree sheet 28—Nzega, N.W. quarter. 1956.

Degree sheet 86—Songea, S.E. quarter. 1957.

Degree sheet 93—Mhukuru, N.E. quarter and part of S.E. 1957.

TATEKAWA, M. 1956. Studies on granite pegmatites. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 223–30.

UEDA, T. 1956. On the biaxialisation of zircon. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 297–304.

UKAI, Y., S. NISHIMURA, etc. 1956. Mineralogical study on manganese dioxide mineral. *Mem. Coll. Sci. Kyoto*, ser. B, **23**, 203–22.

WALKER, A. C. 1955. The excavation of the Kibworth Beauchamp ox. *Trans. Leicester. lit. phil. Soc.*, **49**, 36–47.

WALTON, J. 1956. Rhexoxylon and Dadoxylin from the lower shire region of Nyasaland and Portuguese East Africa. *Colon. Geol. min. Resour.*, **6**, 159–68.

WILCOCKSON, W. H. 1956. Preliminary notes of the geology of Kilimanjaro. *Geol. Mag.*, **93**, 218–28.

WOOD, G. V. 1956. The heavy mineral suites of the Lower Greensand of the Western Weald. *Proc. Geol. Ass. Lond.*, **67**, 124–37.

OBITUARY NOTICES, 1957

ARCHIBALD DONALD BUTTERLEY died suddenly on the way home from his office on New Year's Day 1957. Born in 1896, the younger son of a colliery manager, he was educated at Archbishop Holgate's Grammar School, Barnsley. He decided to become a mining engineer and received his early training at Wharncliffe, Woodmoor and Sheffield University, specialising in electrical and mechanical engineering. His career was interrupted by the war of 1914-18 during which he served in the Royal Navy. On his return he went to Charlaw and Sacriston Collieries in Durham, but in 1928 was appointed Assistant General Manager to the Desford Coal Co. Ltd. in Leicestershire, thus beginning a long connection with the Leicestershire and South Derbyshire Coalfield. The catalogue of his subsequent career, first as General Manager and a Director of the Desford Company, later as Sub-Area Manager, then Area Production Manager under the National Coal Board, his Presidency of the South Midland Branch of the National Association of Colliery Managers in 1947-49 and of the Midland Counties Institution of Engineers in 1951-52, and his services as a Justice of the Peace for Market Bosworth, tells but a small part of his contribution to the life of his district. He was early deeply interested in geology, particularly in its application to mining and was elected a Fellow of the Geological Society in 1927 and a member of the Association in 1938. It was this geological bent which made his schemes of exploration, first at Desford and later throughout the coalfield, so successful. Not least he was ever willing to help others and was never more delighted than when he had an opportunity of demonstrating the many critical sections laid bare during the driving of the Merry Lees Drifts, which he caused to be specially preserved. Above all he was a charming and sterling person who will be deeply mourned by a host of miners and geologists who were proud to call him their friend.

G. H. M.

DR. ROBERT CAMPBELL was born at Auchinblae in Kincardineshire on 1 January 1881. He received his early education at Fordoun, Kincardineshire, and at Hutton Hall Academy, Dumfriesshire, and proceeded to Edinburgh University where he graduated M.A. in 1903 and B.Sc. in 1905. He was appointed Assistant to Professor James Geikie and Lecturer in Petrology in the University of Edinburgh in 1904, and for the next forty-seven years served his *alma mater* with acceptance and distinction. A gifted and successful teacher, Campbell gave generously of his time to administrative duties in the University, and his wise direction and friendly guidance is remembered by a long succession of students. Extramural associations and societies benefited from his skilled lecturing and tutoring, and, in particular, the geological classes of the local branch of the Workers'

Educational Association were deeply indebted to him in the early years of their existence.

While Dr. Campbell's principal research interests are recorded in many petrological papers on the Old Red Sandstone and Carboniferous igneous rocks of Central Scotland, he was the author of important memoirs on the stratigraphy and structure of the Highland Border Series of Stonehaven and Aberfoyle (the latter with Professor T. J. Jehu) and on the Old Red Sandstone succession of south-eastern Kincardineshire. He made, also, notable contributions to the geology of the Pleistocene deposits of north-east Scotland. In 1928, Campbell summarised many years of painstaking research on the composition of the conglomerates of the Downtonian and Old Red Sandstone of the Stonehaven district in a paper read to the British Association Meeting in Glasgow. On his retirement in 1951 he resumed study of these rocks with a view to further publication, but unfortunately he did not live to complete this work.

Dr. Campbell attended a number of the longer Field Meetings of the Association and always looked back with great pleasure to the Norwegian Meeting of 1934, the year in which he became a member. He was known earlier to members for the enthusiastic excursions he led to the Pentland Hills when the Association visited Edinburgh in 1913 and again in 1927; he was responsible for the account of the Pentland Hills, in 'The Neighbourhood of Edinburgh', published in the Association's PROCEEDINGS in 1914 and 1927.

Dr. Campbell died in Edinburgh on 19 February 1957 after a short illness. He is mourned by a wide circle of friends who miss his kind and happy personality.

A. M. C.

PROFESSOR LEON W. COLLET died peacefully at his home in Geneva, 13 October 1957. He was in his seventy-eighth year, and he had been in failing health for some time.

Collet will long be remembered with special gratitude for having opened up to British and American students geological wonders recently recognised in the Alps. A revolution in the interpretation of Alpine structures was introduced in 1893 when Schardt announced the exotic nature of the Pre-Alps that extend either side of the Rhône from Lake Thun to Lake Geneva. This group of mountains is composed of thrust-masses which have travelled so far that their constituent formations, recognised by their fossil content, are of foreign character, or facies, compared with the contemporary, stay-at-home representatives upon which they now lie. Schardt's realisation of this equally amazing and picturesque fact not only solved the long-standing puzzle of localised pre-alpine facies, but also, as he himself clearly recognised, pointed the way to a drastic reappraisal of Alpine structure as a whole. At first almost all Swiss geologists derided Schardt's interpretation,

but after a few years of struggle they one by one capitulated; and under Schardt and Lugeon's leadership they carried through a revision of the geology of the chain, which takes its place on equal footing with the advances made in other sciences in the early years of the twentieth century.

Collet was educated in the University of Geneva, where the battle against the Schardt theory was maintained unusually long. Thus as a young man, Collet had the advantage of having looked carefully at both sides of the question; and to the end he was animated with the enthusiasm of the convert.

Before the change came, Collet, after taking his D.Sc. in 1904, arrived in Scotland to join the temporary, in part international, staff of the Murray-Pullar Survey of the fresh-water lochs of that country. The Murray concerned was Sir John Murray of Challenger fame. As a result he came under the benign influence of Peach and Horne, which left an indelible mark in after years. In part his admiration for these two great men was the primary cause of the delight he found in spreading the story of the Alps through the English-speaking world. His close connection with Murray is also very clearly manifest in two books which he wrote entitled *Les Depots Marins* 1908, and *Les Lacs* 1925, and in his appointment as first Director of the Federal Hydrographical Survey of Switzerland 1912-18. He resigned from this important office to become Professor of Geology and Palaeontology at Geneva (1918-44).

From 1909 onwards, Collet led many excursions to the Alps. One of the most noteworthy was in 1926 when he led a party of the Geologists' Association for ten days, visiting the environs of Mt. Blanc, the Jungfrau and the Matterhorn. It was in the grand style, with four of his University colleagues to assist, and with full consideration for the bodily as well as the mental appetites of his following—he used sadly to admit that his great hero Argand was apt to be forgetful of the former. His account in our PROCEEDINGS (1926, 37, 346-90) is crowded with detail, set forth robustly and attractively. It is essentially a statement rather than an argument. Probably to a Swiss geologist it must have seemed that argument belonged to years already past. It foreshadows *The Structure of the Alps* which appeared next year, 1927, revised 1935, and also the greatest memoir on the Jungfrau, published in combination with Parejas in 1931.

Collet was elected an Honorary Member of our Association in 1938, a distinction which he much appreciated among the many others he received.

E. B. B.

ALEXANDER H. DAVISON was born in Belfast in 1888 and died in his native city on 18 May 1957, aged sixty-nine. He was an estate agent by profession but was intensely interested in natural history. He was an active member of field clubs and natural history societies in Ireland, as well as in other move-

ments, such as the Holiday Fellowship, which has similar interests. Thus Davison was not only a past president of the Auctioneers and Estate Agents' Association of Ireland but he was also a past president of the Belfast Naturalists' Field Club, a Foundation Member (Belfast Branch) of the Workers' Education Association, a committee member of the National Trust (Northern Ireland), and a life member of the Youth Hostel Association. He joined the Geologists' Association in 1935.

J. K. C.

FREDERICK ARTHUR HENSON, who collapsed and died in the grounds of the University of Nottingham on 14 January 1957, was only thirty-eight. Born in 1919 he was educated at Wolverton County School and Reading University from which he obtained degrees in 1940, 1947 and 1950. Like many young men of his age he saw his career interrupted by war service and he spent all but the first few months of the war in the Navy. After early training as a Fleet Air Arm pilot he transferred to the Naval Meteorological Service and served as a staff officer on the personal staff of Admiral Sir James Somerville and Lord Mountbatten. There seems little doubt that he found a job to which his logical scientific outlook, sound judgment and ready acceptance of responsibility were admirably suited. He forecast for all the major operations in South-East Asia, established weather reporting stations on several atolls and was given accelerated promotion for 'initiative and outstanding ability'.

In 1947, shortly after his return from the Navy, he was appointed to the staff of the University of Nottingham and where he ultimately became responsible for the courses in mining geology and photogrammetry.

As a research worker he had many irons in the fire, granites in Jersey, mineral lodes on Dartmoor, ashes from Hekla, geophysics in the Welsh borderland and latterly volcanic rocks in Iceland. Fortunately he wrote as he worked so that the record of his results remain in his many publications. Only his most recent, and perhaps most important, investigations in Iceland remain uncompleted.

A very enthusiastic field worker, Dr. Henson took parties of geologists to many parts of the country and will be remembered most readily by the members of the Association for his joint leadership of the excursion to Jersey in 1955.

Perhaps the most outstanding memory he has left is of his jokes, immensely good-natured geniality, his warm friendship and his reassuring authority. These qualities made him not only a fine teacher, but a valued friend.

R. B. E.

HORACE ALEXANDER LAKE was born in Kingston, Jamaica, on 3 July 1887. He was admitted to practice as a solicitor in 1911 and continued in this profession until his retirement in 1951.

His interests were wide and varied. As a young man he was an all-round sportsman and a first class cricketer and tennis player. In later years he maintained his membership of the Jamaica Lawn Tennis Association of which he was President at the time of his death. His devotion to music and the arts was deep and lifelong. He was Chairman of the Musical Society of Jamaica and of the Musical Competition Festival Committee, and was active in organising concerts by musical celebrities.

He had been a member of the Board of Governors of the Institute of Jamaica, the cultural centre of the island, since 1940, and Chairman since 1950. It was the cultural aspects of geology that led him to apply for membership of the Geologists' Association, for he wrote, after reading an article on the science, 'It is with regret I realise how much I have missed by my tutors not including geology in my school curriculum'. He was elected to membership in November 1955, being one of the earliest members of the Jamaica Group.

Mr. Lake died suddenly on 16 June 1957. He will be sorely missed not only by those who are interested in cultural developments in Jamaica, but by all who came in contact with his charming personality. L.J.C.

ARTHUR LEONARD LEACH was born in Tenby, Pembrokeshire, in November 1869 and died there on 7 October 1957, one month short of his eighty-eighth birthday. For over thirty years he was closely associated with the work and management of the Association and, as excursion leader, officer and President, few have given greater services for so long a period. Significantly for the future historian of Tenby, his father, John Leach, was the local printer and newspaper proprietor. In spite of fifty years' residence in London, he maintained the closest relations with his native town throughout his life.

He was trained as a teacher at Trinity College, Carmarthen, and he took up an appointment as an elementary school teacher in London in 1890. Much of his career was spent at the L.C.C. Elementary School, Ancona Road, Plumstead, where, for a long period, he was far from happy. In fact he confessed to detesting school teaching of the kind that had fallen to his lot, yet he delighted in lecturing to local evening institutions on his favourite subjects. This seems to be a paradox in his character because few could excel him in powers of clear speech and lucid demonstration. The explanation may be that he sometimes found himself in antipathy to the educational authorities and was frustrated by the routine and restricted requirements of the curriculum of his day.

Fortunately circumstances enabled Leach to retire from teaching in 1929, five years before the normal time, and eleven years later he returned to Tenby, becoming the Honorary Curator of the Tenby Museum and subsequently, in 1942, also its Secretary and Treasurer. Here he found work

after his own heart, devoting the rest of his life to the enhancement of the Museum, establishing the local character of its collections, making it the centre for lectures and informal talks and the focus for much archaeological work in Pembrokeshire. It was with pride that he recorded year by year the increasing attendances, swollen during the war by American soldiers from the local camps, and reaching recently an annual figure of 17,000. During his curatorship he issued many pamphlets, special postcards and other publications dealing with the Museum collections, and the history, archaeology and geology of Pembrokeshire. He was also a member of the science committee of the National Museum of Wales.

So much for Leach's career with, finally, its great success in work which he loved. Turning to geology and our Association, we find an equal enthusiasm and zest for hard work. Sometime before 1905 he attended a series of geological lectures at the Woolwich Polytechnic, where he met his friend R. H. Chandler. He joined the Association in 1905, served as General Secretary 1913-18, and as President 1932-34. As Secretary he initiated many useful records and our archives show that he was outstanding in that capacity; on retiring from that office he left carefully prepared note-books on procedure which were much appreciated by his successors. From 1905 to 1939 our PROCEEDINGS contain nearly fifty papers, notes and excursion reports (eight in collaboration with R. H. Chandler), a number by any one author which is almost certainly a record in our history. These publications were mostly on the geology of N.W. Kent and the Pleistocene of the lower Thames Valley, the outcome of constant visits for many years to exposures in Kent, Surrey and Sussex and particularly to the Darent Valley and the dip-slope of the North Downs. Excursions under his sole or joint leadership to Dartford Heath, Crayford, Knockmill, Swanley or like localities were for long familiar items in our field programmes. Between the two wars Leach spent several holidays with Chandler in France, visiting Les Eyzies, the Auvergne, and Brittany, where they explored all the interesting archaeological and geological sites of those areas.

Leach was elected a Fellow of the Geological Society of London in 1910 and in 1926 he was the recipient of the Wollaston Fund, when the President, Dr. J. W. Evans, paid tribute to his local geological work and services to the Association. Our recognition of his work was the Foulerton Award in 1925 and his election as an Honorary Member in 1943. In 1948 the honorary degree of Master of Arts was conferred upon him by the University of Wales.

The list of Leach's publications is very considerable. As a geologist, he provided fifteen papers and twenty-six excursion reports to our PROCEEDINGS and a further three papers and five reports in collaboration with others. Although many were records of half-day excursions, there were more general papers such as 'On the Geology of Shooters Hill' (1912, 1920 and 1930)—the locality of his London home—'On the Dartford Heath Gravel

and a Palaeolithic Implement Factory' (1912), 'The Caves and Rock Shelters of the Vézère Valley' (1924), 'The Geology and Scenery of Tenby and the South Pembrokeshire Coast' (Presidential Address 1933), and 'The Geology and Archaeology of the Isle of Caldey' (Presidential Address 1934). As an archaeologist, he published many papers in *Archaeologia Cambrensis*, including two papers 'Nanna's Cave, Isle of Caldey' (1916 and 1917) and 'The Prehistory of Caldey' (1955), and other notes and papers in *Nature*, *Knowledge* and the *Essex Naturalist*. Many of these papers were illustrated by original sketch-maps, drawings and his own photographs. As a historian, he published 'The History of the Commonwealth (1642-49) in Pembrokeshire and on its Borders' (1937), an 'Account of the Life and Work of Charles Norris' (1949) and the 'Rev. G. N. Smith, a Pembrokeshire Antiquary' (1945)—whose collection became the nucleus of the Tenby Museum in 1878. Also, throughout his life Leach contributed to the local press a stream of articles on the history, archaeology, geology and natural history of Pembrokeshire in addition to the museum publications already mentioned.

Whilst maintaining full intellectual vigour to the last, Leach met with some misfortune in his latter years. He slipped off a ladder in the Museum, injuring a leg so that his life-long habits of exploring and walking long distances were much restricted. The long illness of his wife, culminating in her death in March 1956, clouded the short period of his survival.

In the early decades of the century Leach was one of a group of amateur geologists, in and around London, who worked enthusiastically with and for the Association. These, all friends of Leach, included R. H. Chandler, W. R. Johnson, F. N. Haward, A. S. Kennard, S. Hazzledine Warren, G. W. Young and others, of whom only Chandler survives him. They were typical of the more active members of that period and they were much concerned with the border line between archaeology and geology. In consequence the bulk of their contributions were on the Pleistocene and discussions on the current controversies about flint implements and associated problems were frequent. To these discussions Leach ever insisted on factual observations in the field and showed much caution in correlations not well established.

In character Leach was forthright and direct in speech and thought, always alert and energetic, and a first-class organiser. Although prolific as an author he was most careful and precise in his writing. For example, he held strong views on the use and mis-use of the comma and on the abuse of the word 'meticulous'.

The Association is much indebted to Leach for his services as officer and counsellor and for the long series of publications in our PROCEEDINGS, which alone would be a worthy memorial to his life, but, as has been shown, there was much more which merits our admiration.

For some of the foregoing material the writer is grateful to R. H. Chandler and to three lengthy tributes published in the *Tenby Observer and County News* for 11 October 1957 under the heading 'Tenby's Own Historian'.

E. E. S. B.

LEONARD FRANK SPATH was born on 20 October 1882 and died on 2 March 1957. He had been in poor health for some years, but continued working intermittently at the British Museum (Natural History) until shortly before his death.

He was a world figure in Palaeontology and in Stratigraphy also, since the correlation of the Mesozoic depends primarily on the ammonites he studied. To the many who were inspired by his writings, based on a prodigious knowledge of ammonites of all ages, he was the acknowledged master. To the many who disagreed with him, or with whom he disagreed, he was a splitter, a reckless introducer of new names, typifying 'the modern English school'. His style of writing often invited criticism: especially in his early work he used the polysyllabic jargon introduced by Hyatt and Buckman before him. He often adopted the infuriating technique, perfected by Kilian, of listing faunas by unexplained negative reference (e.g. '*Congoceras belgicum* Smith 1892 pl. XXII fig. 3 *non* 4, *non* Jones 1890'). He habitually wrote as if anyone who disagreed with him was an ignoramus. He seldom resisted the temptation of setting up new names for species of varying ages and areas, which were positively or even negatively related with the particular fauna with which he was dealing.

Yet his many monographs and papers on ammonites from all parts of the world represent a tremendous achievement for one man and a great advance in our knowledge. An output that includes the monographs on the Ammonoidea of the Gault (1923-43), the Jurassic Ammonites from Kachh (1927-33), the Neocomian Ammonites of the Salt Range (1939), the various Mesozoic faunas from Greenland (1930, 1932, 1935, 1936, 1947, 1952), the Ammonoidea of the Trias (1934, 1951) and the Liassic family Liparoceratidae (1938) and dozens of other important works between 1914 and 1956 stands comparison with that of any other student of ammonites.

In the process of preparing his palaeontological work, and indeed as an essential part of it, Spath described, revised or amplified zonal schemes for the subdivision of the strata that yielded his faunas. Because of his great knowledge and the scope of his experience, everything that he wrote on this subject is of importance. Unfortunately, however, much of it is of that indoor speculative type which is liable to be misinterpreted by those who do not understand the methods of the author. Spath, for example, set up at one time or another schemes of 'ages', 'zones' or 'sub-zones' for many of the Jurassic and all of the Cretaceous Stages. Most of these are accepted in their entirety by overseas authors, yet in some cases, as with Buckman

before him, his 'zones' or 'sub-zones' are no more than names of ammonite species put in an assumed order of appearance; there is often little or no basis of a proved succession in one and the same area and no evidence of the practical value of the species listed as zonal indices. Consequently his stratigraphical work, important though it is, must be used with caution.

He was always courteous and kindly to the young enquirer and very ready to help with identification or advice. He gave great encouragement to the many students of ammonites who visited the Natural History Museum to study the great collections that he had made so well known. Relations, however, sometimes became strained with those who published work on ammonites with which he disagreed.

He was never an official member of the museum staff, having refused an offer of establishment in 1919. He joined the Association in 1910 and published a few papers in the 1920s in our PROCEEDINGS and was Director of several Field Meetings but in later years he led a retiring life and was seldom seen outside the museum except by students of Birkbeck College where he was a lecturer.

C. W. W.

JAMES WRIGHT was born in 1878 at Kirkcaldy, Fife, and died suddenly at his Edinburgh home on 28 January 1957. His family, which was of Western Scottish origin, moved to Kirkcaldy in the mid-nineteenth century under the leadership of his great-uncle, who was a celebrated pioneer of improved methods in the floorcloth industry. His father founded his own linoleum and house-furnishing business and James Wright's entire working life was passed in the family firm, from apprenticeship at the age of fourteen until retirement. His geological activities, which led him to international fame, were accordingly entirely a product of his spare time. His father's hobby was astronomy, which was studied in a well-equipped private observatory, but the young Wright's interest in fossils was actively encouraged by the father. As a young man he joined a famous band of Scottish enthusiasts of whom the most notable members were Robert Dunlop of Dunfermline and John Smith of Dalry, and of whom Mr. J. L. Begg of Glasgow is now the sole survivor. With the unsurpassed coastal sections of fossiliferous Carboniferous rocks in Fife at his doorstep, Wright used to rise in the small hours to collect fossils before turning to the business of the day.

Encouragement from the late Dr. F. A. Bather directed his attention to the Carboniferous Crinoidea, a group which would still be almost unknown were it not for his work, and one in which there is at present no one to follow him. Between 1912 and the time of his death he published over thirty papers, of which the largest was a comprehensive study of the Scottish Carboniferous Crinoidea (*Trans. roy. Soc. Edinb.*, 1939). His lifetime's knowledge of the British Carboniferous Crinoidea is embodied in

his Monograph published by the Palaeontographical Society and nearly completed before his death. He was awarded the Wollaston Fund of the Geological Society of London in 1928 and was the obvious choice as first recipient of that Society's Worth Award in 1956. The Geological Society of Edinburgh gave him their Clough Medal (1945-46) and the Royal Society of Edinburgh the Neill Prize (1939). He joined the Association in 1944.

Not the least of Wright's accomplishments was his skill in the preparation of Carboniferous Limestone fossils, made up of long experience and even longer patience. He was often able, after many years, to revise his early work because he had gradually coaxed further details of structure out of specimens apparently hopelessly entombed in hard rock. His unrivalled collection is bequeathed to the Royal Scottish Museum.

He carried his great knowledge with simplicity and modesty and was always generous with encouragement and specimens to younger workers. His humour, which was of the dry Scottish kind, was never used to wound and his natural dignity commanded a respect that he never claimed. In talking to him one felt oneself to be in the presence of strength and wisdom tempered with gentleness, so that with all his eminence as a crinoid-specialist, it is the man himself whose goodness is remembered with affection.

R. V. M.

THOMAS CLIFFORD FITZWILLIAM HALL died at Purley, Surrey, in June 1956, after being a member of the Association for forty-seven years. He was also a Fellow of the Geological Society, a Member of the Mineralogical Society and a Member of the Institute of Mining and Metallurgy.

His wide experience, particularly in economic geology, was gained first as an officer of H.M. Geological Survey; then as a lecturer at the Camborne School of Mines and finally as a geological consultant in Europe, Asia, Africa and the Americas.

After studying geology at the Royal School of Mines and at King's College in the University of London, he joined the Geological Survey in 1903, when he assisted John S. Flett in the Petrographical Department and was concerned with the photographic work of the English division of the Survey. Seven years later he became a lecturer in geology and mineralogy at the Camborne School of Mines where he remained until 1914 when he was commissioned in the Royal Engineers and served in France.

On returning home, after the war, he relinquished his teaching at Camborne in order to take up economic geological consulting work which he then pursued without any significant break until 1950. This work took him to Portugal, Yugoslavia, Korea, Abyssinia, the Gold Coast, Canada and Dutch Guiana, when he acted for the Chosen Corporation, the

Abyssinian Development Syndicate and the Portuguese Department of Colonial Development, among other organisations.

Of his publications one of the earliest appeared in 1912 as a joint paper with Dr. W. F. P. McLintock on the beryl and topaz in the granites of Lundy, Bristol Channel (*Min. Mag.*, **16**, 294–301). At this time he began a detailed study of these granites which he did not pursue. However, when in 1931 Dr. A. J. T. Dollar proposed to make an independent investigation of these and other rocks on the island, Hall, with characteristic generosity, immediately agreed to relinquish his interest in the matter and gave such material aid as he could to the new study. Part of the results of the latter investigation was published in 1941 (*Quart. J. geol. Soc. Lond.*, **97**, 39–77).

Apart from his essentially academic study with Dr. McLintock, his other publications related almost entirely to economic geology. Thus, in our own PROCEEDINGS (1914, *Proc. Geol. Ass., Lond.*, **25**, 180–92), he gave an account of the petrology of the St. Austell Granite, while a paper on nodules in Cornwall also appeared at this time (1914, *Trans. Cornish Inst., Eng.*, **2**, 161–92). In 1921 his Imperial Institute Monograph on lead ores was published, after which a period of twenty-nine years elapsed before he wrote a paper on the coal of Gondwanaland (1950, *Mining Mag.*, **82**, 201–10). Of necessity, the bulk of his geological labours is recorded in the private reports of the several organisations for which he worked.

Somewhat shy for one of his wide knowledge and experience, he was a kind and generous man who will be much missed by his many geological friends.

A. T. J. D.

The death took place at Worthing in January 1956, at the age of seventy-one, of FREDERICK HERBERT VERRALL, a Fellow of the Royal Microscopical Society and since 1920 a Member of the Geologists' Association.

Mr. Verrall was the grandson of Mr. William Verrall, the first Town Clerk of Worthing, an office which he held from before the time of that town's incorporation in 1890 until his death in 1913. His son Mr. W. F. Verrall founded the well-known firm of Verrall & Son, Solicitors, of Worthing, in the early 1870s and his son Frederick Herbert was senior partner in that firm at the time of his death. As a young man he was articled to his father after graduating at Cambridge, and later became his partner. His interest in natural history and geology dated back to his early manhood, when with his father, also a keen naturalist and geologist, he visited many localities of geological interest, at home and abroad, collecting specimens and photographing rock formations. After his father's death, the collections of natural history and geological specimens amassed by him, came to his son, and after his death last year were dispersed, with the exception of a few geological specimens of local interest, which found a home in the Worthing Museum.

In later years Mr. Verrall's interest had turned largely to Scouting and gardening, and his garden included plants from many parts of Great Britain, and from Switzerland. At the time of his death he was engaged in enlarging the rockery to accommodate more of his special plants.

In 1924 he helped to form the 4th Worthing Scout Group and was a Scouter with the Group until his retirement in 1955. Before the last war he was Assistant County Commissioner for Rovers and was responsible for the organisation of the Annual West Sussex Rover Moot. An expert mountain climber, he planned and led many Scout Expeditions to Wales, the Lake District and Switzerland.

A bachelor, he was a quiet retiring man who kept out of the limelight and avoided publicity but held the high esteem of those privileged to know him well. He left an estate of over £99,000, which included a legacy of £2500 to the Worthing Scout Group, to which he had, some years previously, given Headquarters, and substantial bequests to Dr. Barnardo's Homes and other similar institutions, as well as generous legacies to friends, staff and servants.

E. G.

ARTHUR ERIC JARVIS VICKERS died suddenly at the age of fifty-eight on 8 September 1956 in Newcastle-upon-Tyne and was buried at Durham on 12 September. He had been Director of Research of The Thermal Syndicate Ltd., Wallsend, Northumberland, since November 1947 and he was elected to the Board of Directors of the company in April 1953.

Dr. Vickers was born at Stoke-on-Trent on 9 October 1897, and received his early education at The Orme Boys' School, Newcastle-under-Lyme. He attended the City of Sheffield Training College from 1915 to 1917 with a view to entering the teaching profession but afterwards decided to take up chemistry. He studied in Stoke and London and obtained the External B.Sc. degree, University of London, in 1922. In 1923 he joined the staff of the British Refractories Research Association, now the British Ceramic Research Association, Stoke-on-Trent, under the late Dr. J. W. Mellor. He became an Associate of the Royal Institute of Chemistry by examination in 1925 and took the M.Sc. degree in 1926. His experience at Stoke developed his interest in mineralogy, and in 1927 he became Chief Chemist to the Buxton Group of I.C.I. Ltd., Lime Division. He moved from Buxton to I.C.I., Billingham, in 1929, continuing investigations into their refractories problems and in mineralogy, and in 1935 he obtained the Ph.D. of the University of London for a thesis on the colloidal properties of clays. In 1942 he was transferred to Yarm-on-Tees as manager of the newly formed Physico-Chemical Research Section, and was in charge of research work on ceramics and mineralogy. The work involved the application of physical methods in these fields including spectroscopy and microscopy.

Dr. Vickers, who became a member of the Geologists' Association in

1930, was keenly interested in the work of scientific and technical societies, including the Royal Institute of Chemistry (Fellow, 1929), the Society of Glass Technology (Fellow, 1937), the Society of Chemical Industry (Newcastle Section), the Royal Microscopical Society, and the Institute of Ceramics, of which he was a Founder Member. He held various offices in these organisations, including that of Honorary Provincial Secretary of the Royal Microscopical Society from 1949. His published work is to be found in the *Journal of the Society of Glass Technology*, *Transactions of the British Ceramic Society*, the *Journal of the Society of Chemical Industry*, *Transactions of the Institution of Gas Engineers*, *Research*, among others, covering various fields of glass technology, ceramics, and refractories and microscopy. Apart from his professional work, he was a keen amateur geologist, photographer, gardener, and musician; he was also an active churchman (Anglican) and interested in Higher Education. He was a member of the Council of St. John's College, University of Durham.

I am indebted to Dr. K. H. Jack and Dr. J. E. Stephenson of Messrs. The Thermal Syndicate Ltd., through Professor S. I. Tomkeicff of King's College, Newcastle-upon-Tyne, for much of the information given in this notice.

F. H. M.

MICHAEL WYATT became a member of the Geologists' Association in 1948 while he was reading geology at Manchester University. In the final examinations, he specialised in petrology and after graduating with first class honours in 1949, he became a post-graduate student of St. John's College and worked in the Department of Mineralogy and Petrology at Cambridge. In preparing for a higher degree, Wyatt investigated the origin of the Monadhliath granite in Inverness-shire and a gabbro-limestone contact at Camasunary in Skye. Some account of his work in Inverness-shire has been published, with particular reference to zircons as provenance indicators, and a paper entitled 'The Monadhliath adamellite, Inverness-shire' was read to the Geological Society in March 1956. Wyatt was a college prizeman, receiving the Bonney Award in 1950, and his thesis was accepted for the degree of Ph.D. in 1952. After obtaining his doctorate, Wyatt took a teaching appointment at Stanford University, California, which he held until his premature death in September 1956.

Michael Wyatt was a gifted young man with a quick brain and marked ability in self-expression. Apart from his enthusiasm for his particular fields of research, he had a great interest in bird-watching as well as in field geology. Wyatt had a generous and lively personality which was an asset to any social gathering. On both sides of the Atlantic, those who knew him are deeply sorry that his early death prevented him from fulfilling his considerable academic promise.

J. B. A.

The death from 'Polio' of EDWIN ALFRED NELMES has robbed Geology of a promising student. Becoming interested in geology during schooldays he spent much time amongst the geological collections in the National Museum of Wales and in 1953 took Geology at the Advanced Level in the examination for the General Certificate of Education. On the general results of the examination he obtained a Craddock Wells Scholarship and proceeded to the University of South Wales and Monmouthshire, Cardiff but died during the summer of 1955. Had he lived he would have made palaeontology his special interest, and had already shown himself to be a keen and discriminating collector. He became a member of the Association in 1953.

F. J. N.

Order and Disorder in Nature

by C. W. WRIGHT

Presidential Address delivered 7 March 1958

IN THIS Centenary year I thought it opportune to discuss briefly some parts of the philosophical background of our science, geology, and to consider what sort of a thing is natural science.

Nowadays we are generally brought up to believe that the natural world in which we live, and which includes ourselves, is essentially orderly. We are taught that there are such things as Laws of Nature, principles, discovered by scientists, which describe the way in which events operate. We are also led to believe that the discovery of real or apparent exceptions to so-called laws merely serves to spur scientists on to improve or amend the expression of these laws. The assumption is of progress in understanding towards a target of certainty.

On the other hand we also hear today a lot about random motion, statistical laws, uncertainty principles, indeterminacy, chance mutations and so on.

Where is truth or, at least, what is it expedient to believe in all this?

First let us consider for a moment people—other people and ourselves—who hold beliefs about the natural world. We find at once that there are different ways in which individuals and groups—even of the same educational and social backgrounds—tend to look at nature and the universe. Some people are poets, some representational painters, some abstract painters, some mathematical mechanists and so forth. It is interesting in this connection that some sorts of people, by their mental attitude, expressed in spoken or written words, always infuriate other sorts. The humanist may feel that the scientist ignores spiritual values—the scientist that the humanist puts the written word on a level with natural fact.

Why are there these somewhat emotional oppositions between us? I think that the main explanation is that either by heredity or by early environment, or both, most of us are confirmed when we are quite young in one or another way of thinking. We find it uncomfortable that other men, whom we are reluctantly compelled to recognise as rational, have fundamentally different ways of thought. The age at which petrification of mind sets in may vary a good deal but by the time we are grown up most of us have a mental attitude that is unlikely to change much during the rest of our lives.

There are no doubt many types of mental outlook that could be distinguished amongst us, but I am concerned primarily with a single opposing pair of attitudes to nature and the universe that are found among both

scientists and laymen who take an interest in such things. This dichotomy might be thought to throw some light on the views held about what nature is.

We hear a lot about 'science' and 'scientists', but I question the assumption that 'modern scientific man' is or indeed ought to be one single kind of thinking being. Fundamentally, among those who spend their lives considering nature, there are two types, consciously or unconsciously, opposed. Their distinction is not always obvious, for every scientific or other discipline tends to impose on its practitioners stereotyped language, forms of writing and, to some extent, forms of thought. But the two types are generally present.

One type might be described as the active, tidy man, who tends to impose discipline on his subject. The other is more receptive, less tidy, less forceful perhaps in ruling his subject.

Now subjects differ considerably in their suitability for these different minds. Physics, chemistry, astrophysics are obviously the ideal field for the tidy mind. Mathematical relations are the essence here and mathematics the ever-necessary tool. On the other hand, in the biological and geological sciences the tidy mind often goes astray and the passive, unmathematical approach may be more suitable.

The active, tidy and forceful type, of course, is liable to make himself felt, in every way, more than the other, and one detects sometimes a tendency for physics, chemistry and the allied subjects to be regarded as the only really scientific subjects—the only ones in which everything can be quantified and in which most relations can be expressed in mathematical terms. What for convenience we can call the biologist is regarded sometimes as a sort of Stone Age scientist, struggling more or less hopefully towards a distant goal of quantification and 'mathematicification' of his subject. It is, as it were, only by courtesy that such people are treated as scientists.

The biologist generally bothers less about definitions of scientific method, questions of what is or is not science. He shudders perhaps in private at the entry into his field of forceful mathematicians, biometricians, population dynamicists and so forth, but publicly all are welcome. Now I will not deny the immense progress in biological sciences due to biochemists and others who have applied the methods of physics or chemistry, and have made full use of mathematical tools. But a very large part of the biological sciences is and always will be observational and does not necessarily benefit by being expressed in numerical terms.

The question thus arises whether or not there is any fundamental distinction in the subject matter of the two groups of sciences that I have described. Is there some deep difference, for example, between the field of chemistry and that of zoology or geology that is reflected in the type of mind attracted to each? Will the biological sciences in time attain to the

exactitude of physics and chemistry? Is the apparent difference due solely to the different habits of mind of people who become physicists or botanists?

I suppose that there is some element of truth in the ideas behind each of these three questions but there is much more to the matter than this.

The sciences that deal with natural process, geology or geography, or with life, zoology or botany, have an immensely more complicated task than physics or chemistry. In some sense the latter deal with abstractions—with, for example, pure substances or with isolated relations of forces. Faced with what William James called the 'buzzing, blooming confusion' of the perceptible world, such abstraction is essential. The geologist, on the other hand, must use the results of physics, chemistry, meteorology, astronomy and other disciplines in interpreting what has happened in a small part of the earth's crust. The biologist deals with organisms that have a physics and a chemistry, for example, as whole bodies and other sets of physical and chemical relations internally between and within individual cells or between organs of the body.

A mammal has a brain that is immensely more complicated and of vastly greater scope than any computer: this brain and its subsidiary organs control by the most subtle electrical and chemical methods the maintenance of the internal environment of the body, the repair and replacement of its parts, its fuel consumption and its reproduction together with a variety of external relations. This mammal has a history of evolution and must take its place in a system of classification. If the mammal is a man, his study involves also the whole natural history of mind.

Only cosmology, among the physical sciences, can offer problems at all approaching these in complexity: I do not say, advisedly, difficulty or importance, but complexity.

If we grant this, we can frame the question to which I have been leading in these terms:

Is the apparent distinction between the biological group of sciences and the physical group due to a fundamental difference in their subject matter or merely to a vastly greater degree of complexity in the field of the biological group?

Or to put the question in another way:

Is nature divided into two fields, one of which is characterised by an element of disorder, or are there merely many degrees of complexity?

These questions, as usual, depend largely on definitions—it all depends what you mean by so-and-so—in particular, a definition of 'disorder'.

However that may be, my own view is that there is a hierarchy of sciences or aspects of nature: these may differ from each other by whole orders of complexity. The uncertainties or elements of randomness in a first order science like physics or chemistry are greatly magnified in their

effect in a higher order science. Zoology, for example, is so much higher in this hierarchy than the first order sciences, that entirely different tools of thought and methods of study are appropriate. Thus the deductive mathematical approach so desirable in a mathematical physicist is often nothing but a nuisance in a biologist.

As an aside I might suggest that if we believe in such a hierarchy it will be easier to take a balanced view of pronouncements by different kinds of scientists about things in fields other than their own.

But acceptance of such a hierarchy of subjects or sciences doesn't really quite answer the fundamental part of our question so far as it concerns the status of living things. The hypothesis of hierarchy does settle fairly the situation of the sciences of process, as I've called them, geology and geography. Living matter, however, has at present at least one essential characteristic that differentiates it from all else.

This characteristic is the property of the genes, that carry inherited factors, to mutate. To be exact the characteristic applies only to such forms of life as reproduce by methods involving genes—and there are forms of life that don't.

Until fairly recently it was I think generally believed that the occurrence of mutations in the genes of animals and plants was an entirely random process. That is, it resembled somewhat the process by which in a radioactive element a regular proportion of the atoms will in a given time emit a particle and thereby decay or change their nature. It is impossible to prophesy which atoms will decay when, but the rate of decay is rigidly fixed for each such substance.

There used to be talk of general mutation rates, which suggested that people were induced to think that there might be discovered, as it were, decay rates for genes of species or populations or other groups of living creatures analogous to the half-lives of radioactive elements.

Today, I think it is fair to say, we know that mutations can be, and a great many mutations are, caused by the impact of ionising radiations, cosmic rays or the radiations from radioactive substances in the atmosphere or the earth. The widespread realisation of these facts is one of the odder and more useful by-products of the testing of nuclear weapons. It is therefore on the cards that we shall soon come to believe that *all* mutations are caused by radiation or by chemical or other comprehensible factors. If this is so, one more of the peculiar characteristics of life becomes normal and one more item of randomness or disorderliness in nature can be regarded as merely an item of ignorance. In fact the disorderliness of mutation is perhaps mainly or solely the orderly reflection of the fundamentally random characteristic of radioactivity. This, however, though random, can hardly be regarded as disorderly, in any normal sense of the word, for the laws governing the emission of particles of radiation, though

they are in part statistical as I have described, allow predictions that can be and are tested and found correct.

What are we left with? Nature appears to be classifiable in a series of fields, ranging from rather abstract and essentially simple at one end to extremely concrete and essentially complex at the other. The peculiarities of the field of life can be ascribed to the fact that any living organism is by several orders more complex so far as its understanding goes than an astronomical body or a chemical substance. In principle therefore we see no need for any fundamental distinction between living and non-living nature.

What of mind? Here is a whole new subject for the bitterest and most emotional argument. Let me only say that I regard the moment in Greek thought when mind and soul were detached from body as a typical and dreadful example of the ill-effects of the forceful, tidy mind imposing itself on its subject.

How then should we view the position of Geology? I have referred already to our science as one of process, and that applies to its central core. In addition, however, to this central part geology includes the 'fossil' representatives of many sciences, for example, fossil chemistry, biology, botany, zoology, geography, meteorology. This indeed is really a tautologous statement for geology is the science of the earth and its past and consequently comprises the past aspect of all the sciences concerned with the earth as it is today.

So we must conclude that geology holds a very special position. It is really a whole group of sciences, from various levels in our hierarchy, which are unified by a special outlook which I might describe as the sense of time and process.

The implication of what I have said earlier is that nature is one and that there are no fundamental divisions between its different aspects or parts. Yet the differing complexities of these parts and the place of the various sciences in the hierarchy necessitate differing attitudes and lines of approach on the part of scientists. The geologist, brought up to at least a nodding acquaintance with fossil biology, chemistry, physics and geography, should perhaps be better placed than most to appreciate this and to avoid being swept off his feet by the insidious charms of misapplied techniques.

Yet we are not as proof against temptations as we should be. Geology can show many examples of laws and principles to which has been attributed a certainty and scope of application appropriate only to phenomena of physics or chemistry. In my own particular corner, ammonite palaeontology, there are of course some notorious examples of strong-minded men, seized of a good idea, who have beaten and hammered the facts until they have submitted to the hypothesis, which has then been

given the force of law. Indeed, 'ammonitology' seems to run a close second to physics as a breeding ground for the totalitarian outlook.

Repeatedly in palaeontology, and I suggest in most branches of geology, one must refresh and balance oneself by a deliberately passive approach to the facts. The basic description of scientific method as observation, followed by hypothesis, followed by experimental checking, is dangerous if taken too simply. Many lunatic hypothesis based on mistaken or on correct but incomplete observation can be proved by what would pass as experimental checking. I have heard it remarked that there can as well be a unity in falsity as in truth; and self-consistent but false systems of thought can readily be erected. A particular danger, I believe, lies in an oversimplified use of mathematical or statistical methods of investigation, in which obviously erroneous results may be obtained by a selection of only a few of the many relevant factors to be considered. If good results are obtained by the use of any technique, that technique is later liable to be used in the wrong way or the wrong place.

My fundamental point here, however, is that we are always in danger of failing to take nature as we find it, of forcing the facts to fit some notion of our own. To illustrate this I may quote a phrase to the effect that a certain genus of ammonites was too big, in its number of species that is, and therefore ought to be split. In that case, in fact, the total range of morphological variation was relatively small but it was well filled by closely similar though distinguishable species. Now the phrase I have quoted indicates that the author was not facing the facts as they were but, from some mistaken notion of convenience, was forcing the facts to fit a mental concept of his own.

In short we are led to the position that nature is a single whole—that is, that there are no fundamental divisions between its different aspects; that there is consequently no separation between an orderly or mathematical and a disorderly or non-mathematical part of nature; but that the treatment appropriate to one level of complexity among the sciences is not necessarily appropriate to another and that the basic assumption of order in nature is no justification for failing to accept the facts as we see them.

This indeed is the essential point. Our methods of thought are largely conditioned by the tools we use—words, syntax, mathematics. Consequently we are always in peril of pouring the facts into our currently fashionable set of containers and then ignoring what doesn't fit or is spilt over. The basic assumption of order and regularity in nature is equally a tool of our thought: it must not be elevated beyond that. The world is as it is and was as it was and all the argument of clever men cannot alter one fact. Unfortunately it can sometimes prevent us seeing or understanding the fact.

A Centenary Lecture: Stratigraphy in Metamorphism

by H. H. READ

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ABSTRACT: In this examination of the employment of stratigraphy in metamorphic geology, stratigraphy is taken to include not only its usual historical content but also the 'study of strata' as raw materials for metamorphism and plutonism. The importance in metamorphic geology of the primary characters of sediments is emphasised and examples are given employing primary mineralogical, chemical, textural and structural properties on the one hand and geological properties on the other. The profound revolution brought about in metamorphic geology by the demonstration of valid sedimentary successions is described. Contrast is made between the sedimentation in mobile and in stable segments of the crust, and the nature and meaning of geosynclinal infillings are discussed. Throughout, the moral is drawn that the more a metamorphic geologist knows about his sedimentary raw materials, the more likely is he to be right in his interpretations.

1. INTRODUCTION

I MUST first thank the Council of the Geologists' Association for the honour they have done me in considering me worthy and capable of delivering a Centenary Lecture. On this occasion, my choice of subject is governed by a combination of two factors: what my interests are and what the interests of most of my hearers are likely to be. I have therefore to produce a hard-rock soft-rock hybrid—I trust a less polite term will not be applied to what I have to say. As I survey the course of plutonic geology over the last thirty years and note the complete change in our outlook on the geology of the metamorphic rocks, I have to subscribe more and more to J. M. Weller's dictum that 'stratigraphy is the basis of all geology'. Admittedly, the stratigraphy used by the plutonic geologist is

often somewhat peculiar but it is the best he has available. It may thus be of interest to members of this Association, whose rocks obey both of William Smith's famous Laws, to hear what can be stratigraphically done with rocks to which neither of the Laws applies.

Of late years, I have become more and more impressed with the importance of the original characters of rocks in their subsequent metamorphism and plutonism. Stratigraphy, I agree, is largely concerned nowadays with the historical aspects of the sedimentary rocks amongst themselves and what I have to say is to some degree so concerned. But tied up with their later history especially are those original characters whose examination, after all, might properly be included in any 'study of strata'. Accordingly, I begin with an excursus into strata considered as the raw materials for metamorphism and plutonism.

2. PRIMARY CHARACTERS AND THEIR IMPORTANCE

By primary characters is meant the significant properties of a rock present when plutonic processes begin to operate on it. These characters are of two broad kinds: first, lithological characters such as mineralogical and chemical compositions, texture and structure and second, geological characters such as bedding, sequence, association and relation to neighbouring rocks.

Only when the primary characters of a metamorphic rock are established can its history be decisively deciphered. As an example, the structural evolution of a complex of metamorphic rocks is only satisfactorily determined if their stratigraphical order can be demonstrated—and this can be done only by the use of primary sedimentary characters. The more the primary characters remain in a rock, the better will its metamorphic and plutonic history be established. This aspect of metamorphic geology cannot be over-emphasised. Indeed, this branch of geology rests on tracing non-metamorphic into metamorphic rocks; in most cases, the actual transitions are no longer available and the best that can be done is to deal with relics of primary mineralogical, textural or structural characters.

3. PRIMARY MINERALOGICAL AND CHEMICAL CHARACTERS OF SEDIMENTARY ROCKS

Sedimentation processes result in a sedimentary differentiation, both physical and chemical, whereby the parent igneous rocks provide four great classes of sediments of interest to the metamorphic geologist. These are the pséphites, psammities, pelites and carbonates. Some of you may doubtless regard the first three names with no great affection, but I would remind you that they were introduced more than a century ago by no lesser figures than Häuy and Naumann. In these sediments, the mineral components are inherited or new, chief among the latter being the carbonates

and the clay-minerals. The inherited minerals appear in the psammitic and coarser types. The metamorphic geologist is beginning to be interested in a special group of inherited minerals, the so-called heavy minerals, especially zircon. He has to consider whether or not heavy minerals can survive in recognisable condition during the often drastic operations of metamorphism and plutonism. In this connection, I would mention the work of Brammall and the more modern, very thorough, explorations of the subject by Poldervaart and his school.

The psephites include the conglomerates, breccias and tillites or boulder-clays. Two kinds of conglomerate are worth distinguishing, first the oligomict made of one stable kind of pebble of an obdurate type such as quartzite and representing beach-deposits advancing on a base-levelled land and, second, the polymict, with a variety of pebbles of unstable rocks undergoing decay and most likely formed by rapid deposition of material worn quickly from high mountains. This two-fold division in the psephites is applicable in the psammites and for the same genetic reasons; first are the quartz sands or orthoquartzites, well-sorted and running to over 90% silica in some samples, and second are the greywackes, badly sorted, of mixed grains and grain-sizes. The pelites are the clay-rocks and, like the limestones and dolomites, need no further comment.

It is important in plutonic geology to realise the relative abundance of the sedimentary classes; estimates are:

	<i>Psammites</i>	<i>Pelites</i>	<i>Carbonates</i>
Clarke	15	80	5
Holmes	16	70	14
Kuenen	20	65	15

Though these estimates may be open to criticism, the dominance of pelites is undoubted. Recently, Poldervaart (1955) has made an estimate of the relative abundance of sediments in the young foldbelts of the crust with these results: Shale 56.5%; sandstone 14%; limestone 24%; greywacke 5.4%.

This dominance of pelitic rocks in the foldbelts is important in metamorphism and plutonism, as is also the extreme composition of the psammites and limestones. These aspects will be appreciated from the consideration of the chemical composition of the sedimentary rock-types.

Gross estimates of the chemical composition of the sedimentary rocks are of value to the plutonic geologist provided he recognises the possibility of considerable divergences from them. In broad terms, attention may be directed to the following primary chemical characteristics. The orthoquartzites have a very high silica content. The greywackes have a lower silica percentage and are, besides, comparatively rich in the oxides derived from felspar; ferrous iron exceeds ferric, lime exceeds magnesia, soda

exceeds potash—these ratios are in keeping with their origin and with the time of their formation in the orogenic and plutonic drama, as we see later on. Arkoses show dominant potash over soda and are clearly rocks of a different provenance and origin from the greywackes. In the pelites, silica is high, alumina is high and approximates to the average of igneous rocks, potash exceeds soda except in the shale-like members of the greywackes.

The chemical composition of metamorphic rocks can legitimately be used as a criterion of their origin; but there is no guarantee that the primary chemical composition is retained during metamorphism and plutonism. Bastin (1909) long ago proposed certain chemical criteria, but there are many metamorphic rocks of sedimentary origin that do not obey his rules.

Whilst it is true that no sedimentary rock has the exact composition of an igneous rock, it is equally true that some sediments approach igneous rocks in composition. Where the mechanical breaking-up combined with rapid transport and deposition does not permit much chemical weathering, the products such as the greywackes do not differ widely in composition from the average igneous rock. The same is true for the pelites in general. In plutonic operations therefore we may expect the sedimentary raw materials to behave as two groups. The first, such as the quartzites and limestones, are of such extreme composition that they require great expenditure of material and energy to transform them into anything like an igneous rock—these are the resisters. The second group, semipelites and pelites, are the non-resisters, much nearer to igneous rocks in composition and so needing little chemical reaction and interchange to transform them. This primary contrast is still discernible in many very advanced stages of plutonism.

It must be restated that the knowledge of the primary composition of the sedimentary raw materials controls the validity of the interpretation of many plutonic processes. Two questions are repeatedly asked in plutonic geology: what was the primary composition of the raw materials and has this primary composition remained unchanged during metamorphism and plutonism? Answers are usually difficult and often diverse. A couple of examples of these enquiries are the following. Certain granites are considered by some to be the result of granitisation of country-rocks during which material has been expelled from the area being granitised and has come to rest in the peripheral country-rock to form a basic front. A demonstration of such a transfer can be secure only if based on a complete knowledge of the chemical compositions of the country-rocks concerned; interested readers may consult the discussion of the Hangö granite in Finland by Niggli (1946). In this kind of enquiry original compositional variation may be of fundamental importance, as shown, for example, by Pitcher & Sinha (1958) in the aureole of the Ardara granite in Donegal. Again, the contrasted interpretations of the albite-gneisses and of the rocks

said to be felspathised depend on whether or not the composition of the country-rocks is regarded as unchanged during plutonism.

4. PRIMARY TEXTURES OF SEDIMENTS

Primary textures of sediments, being geometrical patterns, are invaluable to the metamorphic geologist in that their modification records the deformation that accompanies the production of some metamorphic rocks. Small-scale textures are often obliterated, but large-scale textures, in which pebbles, blocks or fragments are involved, often provide evidence of value.

In a metamorphic rock, sporadic grains of one mineral set in a dominant matrix of another may give a clue to the primary grain-size of the original sediment. An example of the importance of the primary shape of a sedimentary component is given by Cloos' (1947) work on the deformation of oolitic grains. It is doubtful whether any primary preferred orientation remains in metamorphic rocks of any advanced grade and usually it can be ignored, since in fabric studies in metamorphic derivatives a large number of specimens from a wide network of stations located over a considerable vertical interval in a variety of rocks have to be dealt with.

Psephites and Pseudo-Psephites

Rocks composed of large rock-fragments, pebbles or blocks set in a groundmass varying in kind and amount may arise by processes other than those of sedimentation—there are accordingly psephites and pseudo-psephites. Moreover, true psephites may have their primary characters greatly modified during metamorphism. This class of rocks thus provides interesting problems in metamorphic geology.

Primary shapes of true psephite pebbles can be described by Zingg's (1935) method, in which the ratios of breadth to length and of thickness to breadth are employed. An immediately useful measure is the sphericity, given by the ratio of the diameter of a sphere having the same volume as that of the pebble to the diameter of a sphere circumscribing the pebble—the latter being of course usually the length of the pebble. Flinn (1956) measured 126 quartzite pebbles in a modern beach in Shetland and found a sphericity of 0.71; in an undeformed Devonian conglomerate in Shetland, 203 pebbles gave a value of 0.76; the sphericity of the least-deformed pebbles in a metamorphic conglomerate in the island of Fetlar was 0.56 and many of the pebbles were disc-like—a secondary shape had been superposed on a primary.

Pebbles of a conglomerate may show a primary fabric such as an alignment of their long axes in the direction of the operative current, but it seems to me doubtful if such primary features have to be taken into account in the investigation of strongly deformed conglomerates—but

everyone must use his own judgment. Imbricate arrangement of pebbles has certainly been used by Pettijohn (1930) in the Archean conglomerates of Ontario.

Till is an important raw material in metamorphic geology, both because of its distinctive primary characters and of its physiographic and stratigraphic implications. It is possible that the primary oriented till-fabric may have to be considered in the interpretation of the deformation-history of ancient tills or tillites. Whether or not a tillite-like bed is of proved glacial origin does not lessen its value as a key-horizon to the metamorphic geologist. A celebrated example of this is the Schichallion Boulder Bed in the Dalradian of Ireland and Scotland, traceable at intervals from Donegal in Ireland to Banffshire in Scotland, a distance of 250 miles. There can be little doubt that a variety of psephitic and pseudo-psephitic rocks have been too readily interpreted as tillites, even in non-metamorphic assemblages. Slumping and sliding on the one hand and deformation of beds of differing strengths on the other can lead to a tillite-like association of large and small blocks sporadically dispersed in a fine matrix. Thus, an unstratified and unsorted conglomerate of Permian age in Northern Mexico has been called a tillite by some and a tectonic conglomerate by others; Newell (1957) has recently shown that it is most likely the result of submarine sliding under gravity. Some pebbly mudstones have been called tillites but are better also ascribed to gravitational sliding.

Pseudo-psephites are produced in a variety of ways and comprise such rocks as fault-breccias, crush-conglomerates and tectonic melanges. No general criteria can be given for the distinction of pseudo-psephites from sedimentary conglomerates and breccias in metamorphic terrains. The identification in each case will depend on observations of such matters as the lithology of the melange, the relation of fragments to matrix, transitions to neighbouring rocks and, of course, fundamentally on the relation to the regional stratigraphy and structure. As a case in illustration, I may give Gillott's (1956) re-examination of the celebrated 'crush-conglomerates' in the Manx Slates. Gillott points out that normal banded sediments are interbedded with the 'crush-conglomerates' with conformable contacts, that the 'crush-conglomerates' predate the cleavage and metamorphism and that they occupy a definite position in the Manx Slate sequence—they are to be interpreted as the result of sub-aqueous sliding during sedimentation and are not of tectonic origin.

5. PRIMARY STRUCTURES OF SEDIMENTS

The most important primary structures of sediments are those of bedding of all kinds—important to the metamorphic geologist not only because they supply evidence concerning the style, order and setting of the sedimentation involved, but especially because bedding often gives a

datum plane against which to measure later accidents. For our purpose, a bed is the product of one act of sedimentation, and originally formed an almost flat sheet bounded top and bottom by bedding-planes. A bedding-plane was for an instant of time the outer surface of the lithosphere and represents a pause in the sedimentation—a pause ranging from the time between successive high tides to some thousands of years. Four types of bedding are of interest to the metamorphic geologist, namely regular bedding, current-bedding, graded bedding and slump-bedding.

Regular bedding simply means what it says. An assembly of regular bedded rocks may present a spectacular striped or banded pattern of remarkable constancy. Among the metamorphic sediments, similar regularities are found and the question has been posed as to how far such assemblies then represent regular bedding. We return to this point later when we discuss the validity of bedding in general in metamorphic rocks.

In current-bedding, the deposition-lenses are inclined from the start, being built-up one in front of the other and separated by curved deposition-planes. These planes meet the floor on which the set is laid down at a gentle angle, giving an asymptotic bottom to each lens. The depositional planes are inclined down current, a circumstance allowing the determination of the direction of the water or wind currents that moved the materials. Researches on non-metamorphic rocks along these lines that should be studied are those of Shotton (1937, 1956) on the British Trias, Reiche (1938) on the Permian Coconino Sandstone of Arizona, and Potter & Siever (1956) on the basal Pennsylvanian of the Eastern Interior Basin of the U.S.A. This palaeocurrent work has potentialities in metamorphic geology. For example, Pettijohn (1957) has shown that during the deposition of the Pre-Cambrian quartzites of the Lake Superior region, currents flowed from the present north-west to the south-east and exhibited an extraordinary stability in space and time. Pettijohn uses the palaeocurrent direction to discuss the much-disputed question of the correlation of two of the great Pre-Cambrian units of Eastern Canada, the Grenville and the Huronian, and is led to suggest that these units are equivalent. Again, in Scotland, the equivalence of the Torridonian Sandstone to the west of the Moine Thrust and the metamorphic Moine Series to the east has been a subject for continuous debate. Wilson, Sutton & Watson (1953) have assembled the scattered and somewhat scanty data on palaeocurrents in the two formations and find that the deduced directions are completely opposed. They accordingly conclude that the two formations are either not equivalent or, if they are, they were formed in widely separated parts of the same basin.

The primary inclination of the deposition-planes in current-bedding cannot exceed 32° , the angle of rest of dry sand in air. A greater inclination records a deformation, either of the current-bedded series as a whole or of individual sedimentation-units with reference to their neighbours. A nice

example of the use of the depositional planes in the recognition of internal shearing is provided by Pettijohn (1957) in the Lake Superior quartzites already mentioned. The primary attitudes of the depositional planes on the two limbs of a fold are shown to have been modified in accord with the deformation.

But of course the present main interest of current-bedding for the metamorphic geologist rests in its use for the determination of stratigraphic order. The series of depositional planes becomes cut across by an erosion-plane so that they now have truncated tops. This combination of depositional planes, with their asymptotic bottoms and truncated tops, and erosional planes is of the greatest importance in metamorphic geology as it can often be recognised in completely recrystallised rocks. It must be emphasised that discordances of various magnitudes may be brought about between laminae or beds by deformation, and the field-geologist must be convinced that he is looking at a primary truncated top and not a secondary dislocation. A few good reliable observations are of the greatest significance; a multitude of doubtful, possible or likely observations is of no value whatever.

In graded bedding (Bailey, 1930) there is a transition in grain-size of the constituent particles from coarser at the bottom of the bed to finer at the top, a structure well illustrated in the greywackes. Individual graded beds may vary from a fraction of an inch to as much as 15 feet (Sutton & Watson, 1955) and often build up great sequences. As we see later, the greywacke type of sedimentation marks a special episode in the orogenic drama.

Bailey (1930, 1936) in two classic papers showed that graded bedding in general resulted from the settling of detritus through deep water. The sudden delivery of great quantities of detritus into deep water is achieved by turbidity currents (Kuenen & Migliorini, 1950). Masses of unconsolidated sediment are believed to slide, perhaps near the continental slope, and to pass into turbidity-currents which, when checked, deposit their load in a graded accumulation, badly sorted throughout.

From its manner of formation it is obvious that graded bedding provides another method of determining the stratigraphical order of a succession of beds, the coarser part of each bed indicating the primary bottom. Other evidence from some graded beds permitting the same determination is provided by convolute laminations and erosion surfaces (Richey & Kennedy, 1939), but extreme care is needed in metamorphic rocks to ensure that primary relations are being observed. The various types of sole-markings, the study of which is now fashionable, might be used in metamorphic rocks to determine palaeocurrent directions, but no cases of such use are known to me.

Slump-structures result from the sliding on the sea-floor of unstable

masses of alternating sediments with the mixing of the beds involved so that, for example, large blocks of coarse material are scattered through fine, or the reverse. Dislocation of bedding, leading on to rupturing, kneading and balling-up of the various beds, produces a pseudo-psephite that requires careful handling by the metamorphic geologist. Richey & Kennedy (1939) have described slump-folding in the Moine Series, and Sutton & Watson (1955) in the Upper Dalradian of Banffshire, where slump-sheets may reach 50 feet in thickness. It is clear that these primary melange structures may simulate not only other primary structures, such as those of the true psephites, but also pseudo-psephites due to later deformation. In the interpretation of melanges of any kind, care must be taken to examine all the local evidence, especially that presented by the associated beds. The geological structure or tectonics of the region may supply a check on any interpretation and must be considered simultaneously with the sedimentary and stratigraphical evidence. I recommend once again Gillott's paper on the Isle of Man 'crush-conglomerates' as an example of the procedure. Slump-sheets are associated most often with greywackes, and slumping and turbidity currents are symptomatic of the same unstable environment of sedimentation.

Ripple-mark may prove of interest to the metamorphic geologist. Richey & Kennedy (1939) have recorded ripple-marking in the metamorphic Moine Series of Morar, but direct attention to the fact that ripple-mark can be imitated by secondary tectonic structures. It is indeed very probable that some ripple-mark recorded from metamorphic rocks may be such pseudo-ripple mark (Ingerson, 1940). Ingerson has established fabric criteria for pseudo-ripple mark; as was to be expected, the quartz fabric in pseudo-ripple mark is directly related to some structural direction such as an axis of folding. Mica flakes perhaps had a primary sedimentation fabric and should be left alone. Various kinds of structures can simulate ripple-marks; the first point the metamorphic geologist has to establish is whether the structure is a surface feature on one bedding-plane or whether it affects a whole succession of lamination surfaces. The validity can usually be assessed in the field.

6. BEDDING AND BANDING, THE BEDDING-PLANE AND OTHER PLANES

The fundamental necessity of determining primary bedding and bedding-planes in metamorphic geology cannot be over-emphasised. During metamorphism and plutonism there may, however, be produced certain secondary planar structures that closely resemble these primary structures. The validity of any structure called bedding in metamorphic rocks must be closely scrutinised.

The preservation and recognition of bedding in the metamorphic rocks were the basis for the erection of this group by Hutton and Lyell. Alternations of layers of different composition, colour and thickness in the metamorphic rocks were so like those of ordinary sediments as to 'leave scarcely any reasonable doubt that they owe this part of their texture to similar causes' (Lyell, 1833, 3, 10). In many cases, experience shows that this conclusion must be correct, a conclusion often reinforced by the recognition of correctly placed graded or current bedding. In metamorphism, in fact, bedding and bedding-planes often become emphasised or simplified by mimetic crystallisation in or along them. On the other hand, these primary structures can be destroyed, and it has often been asserted that bedding and bedding-planes are rarely seen in metamorphic rocks. A century ago, Charles Darwin himself (1846) considered that much of the so-called stratification of the crystalline schists was not true bedding but was due to a process of segregation or concretion; he admitted, of course, that layers of marble and quartzite were true sedimentary beds. Lehmann (1884), the great Saxon metamorphic geologist, likewise held that banded and striped structures in metamorphic rocks were usually due to shearing. He described examples of banding that simulates the bedding of sediments but which is undoubtedly produced by intense movement along thrust-planes. We may here recall that Lapworth held that in the Moine Series of Scotland there were no planes of deposition preserved but only planes of shearing and cleavage—these produced a pseudo-bedded appearance. The opinion of these great masters has been reiterated by many workers. Balk & Barth (1936) have restated Lehmann's position and have concluded that 'statements that alternating layers of different colour, each characterised by different mineral composition, are due to original stratification of the rock should be looked upon with suspicion'. Similar views are held by many workers among the crystalline schists.

It is accordingly imperative for the field-geologist to decide what are the banding and planar structures he is observing in the metamorphic rocks. The correct answer may come, unfortunately, only with experience, but this experience is one of detailed, local observations fitted into the regional structural picture; the stratigraphy and the structure of the region must fall into a consistent and complete pattern.

Certain types of very regular banding or striping in the metamorphic rocks have been interpreted by Schmidt (1932) and Wenk (1937) as due to a mechanical sorting of mineral grains during deformation and metamorphism, a sorting controlled by the different capacities of translation of minerals under such conditions. This 'Örtsregelung' may occur, but it cannot have occurred in rocks in which minute and delicate primary structures are preserved. Indeed, the erection of valid stratigraphical sequences by the use of sedimentation characters indicates to my mind

that much of the banding of the metamorphic rocks is bedding; Lapworth's view of the Moine Series as a purely mechanical assemblage is shown to be wrong by the discovery of innumerable primary structures by which lengthy stratigraphical sequences have been established.

7. PRIMARY GEOLOGICAL CHARACTERS OF SEDIMENTS

The primary geological characters of beds involve both time and space and these stratigraphical aspects are of growing importance in metamorphic geology. The two Laws of William Smith are unfortunately here of very restricted application. The second Law, 'of Strata identified by Fossils', has little meaning for rocks in which fossils either never existed or have been completely destroyed. The first Law, 'of Superposition', that states that the bed originally at the bottom was the older, is valid only when no inversions have taken place—and inversions are common in metamorphic terrains. Fortunately, we have other means than simple superposition to determine the stratigraphical order of our rocks.

It is doubtful if disconformities are validly recognisable in many metamorphosed sedimentary rocks where the possibility of movement between bed and bed is considerable but, of course, unconformities as in more normal stratigraphy are of profound significance. An unconformity is often of importance to the metamorphic geologist in that it supplies another datum, both of time and of place, against which to measure plutonic events. The relations of an unconformity to such plutonic operations as orogenic folding, metamorphism, granitisation, the emplacement of granitic bodies of various kinds are of the greatest interest, as too is what was being supplied from where and to where in the making of the unconformity. The surface of unconformity between the basement and cover can be used for assessing subsequent movement of the foundation; its study shows that the basement is commonly rendered plastic and mobile during later orogenic and plutonic happenings. By such means, Eskola (1949, 1952) in his mantled gneiss domes has shown that the gneiss of the domes is intrusive into the sediments of which it is the basement.

8. SEDIMENTS IN TIME

In metamorphic geology, it is necessary for correct interpretation to establish two things about a sedimentary succession, first, that the series of beds is really a straightforward sedimentary sequence with the individual beds still bearing their primary relation to one another and, second, that a stratigraphical succession giving the age-sequence is determinable in the set of beds concerned.

(a) Establishing the Sedimentary Succession

When a set of beds of varying strengths is folded to different degrees, different stages of admixture, shuffling and rearrangement may be achieved. With really violent concentrated movement, a mechanical sequence may be produced—such is believed to be the case by some metamorphic geologists in certain areas. It may therefore be wrong to assume without careful thought that a given sequence of metamorphic beds represents a primary sedimentary succession.

There is no ready-made test that can be applied to settle this matter. The total geological picture of the area has to be taken into account, so that the behaviour of the individual beds can be determined to be congruent or not with a true sedimentary succession. Much can be done by careful observations of transitions or passages between two lithological types that inseparably connect the two types of deposition without a break between them. A multiple bracketing of several lithological types supplies a sure test. An example of this is provided by the distribution of the lithological variations in the Upper Dalradian rocks of the Banffshire Coast-section (Read, 1923; Sutton & Watson, 1955). Here certain rock-types, such as calcareous grits, pebbly grits, calcareous flags and pelitic beds (now represented by andalusite-schists) link the whole 9000 feet of sediment into a continuous succession. This is brought out in the table below:

	Predominant Rock-type	Subordinate Rock-type	Thickness feet
MACDUFF GROUP	Greywackes	Slates, grits	4000
BOYNDIE BAY GROUP	Greywackes	Slates, andalusite-schists, grits	1500
WHITEHILLS GROUP	Siliceous grits	Andalusite-schists	4000
	Calcareous grits	Siliceous grits, calc flags, andalusite-schists	1000
	Calc flags	Siliceous grits, calc grits, andalusite-schists, limestone	1700
BOYNE LIMESTONE	Limestone	Calc flags, mica-schist	1000

Bracketing on the Banff pattern is reliable evidence of transition and there are, of course, innumerable examples in the metamorphic rocks where unbroken successions of a primary character have been established.

(b) Establishing the Stratigraphical Order

The determination of the stratigraphical order in a succession of metamorphosed sedimentary rocks is essential for a complete solution of the geological structure of the area—the rule must be: stratigraphical order first, geological structure second. The two methods employed in practice among the metamorphic rocks are those involving graded bedding and

current-bedding, already described. During the last quarter of a century, the employment of these criteria has revolutionised the study of the metamorphic rocks. A few selected examples will illustrate this.

In 1897, Sederholm of Finland first applied the uniformitarian method in his classic study of the Archean metamorphic rocks of the Nasijärvi area near Tampere in south-west Finland. The chief rocks concerned were banded varve-like phyllites that are, in fact, excellently graded greywackes which would have provided the key to the succession and structure of the area had Sederholm known the modern tricks. Bedding in the sedimentary pile is now vertical and Sederholm concluded that only simple tilting had affected the whole assemblage. New work on the Nasijärvi area by Neuvonen, Matisto, Seitsaari, Simonen and Kouvo has been summarised by Eskola (1953). By the use of graded bedding, a stratigraphical succession of some 8000 metres has been established and large-scale and small-scale folding demonstrated. A complete solution of the stratigraphy and structure of this area of metamorphic rocks is based on graded bedding.

Graded bedding can be employed in completely recrystallised metamorphic rocks because of the differences in the primary chemical composition of the sandy or silty bottom part of a graded bed and the more clayey upper part. The varved beds of the Nasijärvi Archean just mentioned provide an illustration. Eskola (1932) has given analyses of the coarse bottom part and fine upper part of one varve, with the results for the chief oxides as below:

	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃	FeO	MgO	CaO	Na ₂ O	K ₂ O
Shaly Top	55.63	1.04	22.41	0.58	5.05	2.35	1.28	2.31	6.15
Sandy Bottom	63.93	0.82	16.92	0.79	5.04	2.12	1.36	1.98	4.94

The main differences are seen to be in the silica, alumina and potash contents. On metamorphic reconstruction, these primary differences will be expressed as mineralogical differences that are usually sufficiently striking to be readily apparent in the field. A good example comes from the Upper Dalradian of the Banffshire Coast (Read, 1936). The Boyndie Bay group is there formed of alternating pebbly grits and greywackes, the latter being represented by coarse andalusite-schists. The distinct beds of andalusite-schist show little or no andalusite at their primary bottoms—determined to be so by the grading in the associated pebbly grits; upwards in each bed andalusite begins to appear, first as a few crystals then in greater abundance, till at the primary top of each bed the rock is composed of granular andalusite in large crystals. Here is exactly recorded the primary chemical differences already displayed.

In this Banffshire example, since the andalusite occurs in large porphyroblasts, the top which was originally the finest part of the bed becomes on metamorphism the coarsest portion. On metamorphism, the grading in

grain has become reversed—we may call this metamorphically reversed grading; it is constantly in use in such terrains as the Donegal Dalradian.

The profound effect that the establishment of a reliable 'way-up' technique had on the interpretation of structure in metamorphic terrains is well illustrated from the Dalradian of the Ballachulish district in south-west Scotland. A collection of three classic papers by Vogt, Tanton and Bailey (1930) should be consulted. Tanton provided a general account of age-determination in folded rocks; Vogt by using current-bedding established the stratigraphical order of the Ballachulish Dalradian; Bailey extended Vogt's observations and reinterpreted the Ballachulish structure. The major slides became lags and not thrusts, the Ballachulish recumbent fold was a syncline and not an anticline and the operative movement came from the south-east and not the north-west. Farther afield, great inversions were established in the Kinlochleven region, and what had previously been taken to be infolds of one quartzite were shown to be separate and independent quartzites vastly extending the Dalradian succession downwards. A new principle had been presented to the metamorphic geologist which was as valuable in its way as William Smith's Laws were in the more orthodox kind of stratigraphy.

9. SEDIMENTS IN SPACE

Sediments being deposited at one time necessarily vary in character from place to place, depending on the varied environments of sedimentation; they show facies changes. It is interesting to recall that Gressly's original use of this term was in connection with the contrast between the violently deformed and metamorphosed Alpine Jurassic with the less-modified rocks of the same age in the Jura. These contemporaneous beds had different lithologies and faunas, but not only so—and this is where the interest of the metamorphic geologist is aroused—they had suffered markedly different fates in the subsequent Alpine orogeny.

How far is the metamorphic geologist to be concerned with change of facies in metamorphic terrains? His units are entirely lithological and the true time-equivalence of different lithological formations can rarely be established in metamorphic ground. Theoretically, and maybe somewhere practically, a change of facies in a metamorphosed sedimentary series might be determined if the horizon in question were sandwiched between two constant key-beds sufficiently remarkable to allow the three-fold succession to be followed over a reasonable area; changes in the median bed of the sandwich might possibly be due to primary changes of facies.

But exactly this technique has been used to demonstrate secondary compositional changes superposed on an originally uniform bed during metamorphism and migmatization (e.g. Cheng, 1944). It seems therefore

that the metamorphic geologist has perforce to assume that thinnish beds may keep their facies unchanged for considerable distances along the strike and that change of facies is not often to be demonstrated in the metamorphic rocks. He is, of course, immensely interested in difference of facies, the contrast between great thicknesses of sediments of one lithological type and great thicknesses of another type; such contrasts indeed have a profound significance in the metamorphic and orogenic drama. But change of facies in individual beds seems to be beyond our grasp at present.

The importance of characteristic, readily recognised, key-beds in metamorphic geology needs no emphasis. An index bed is invaluable in this as in other geology for the determination of the geometry of a series and especially for correlation. Key-beds become important in the day-to-day mapping of metamorphic rocks; their presence affects not only the detail and the validity of the ultimate map but also the enthusiasm and energy of the mapper. On them are often bestowed affectionate nicknames, 'ermine rock', 'tiger rock', the 'spangles', 'spotted dog' and the like that are a measure of their diverse values. Of course, a key-bed is better described as a key-series and this is often a sedimentary rhythm. But rhythms in metamorphic geology have to be used at present in bulk and are then invaluable. Rhythm has been described by Richey & Kennedy (1939, p. 29) in the Moine Series of Morar; here the Upper Striped Schist shows innumerable repetitions of a rhythm with these details:

		inches
COMPOSITE RIB	{ Grey psammitic layer	3
	{ Calc-silicate layer	$\frac{3}{4}$
	{ Grey psammitic layer	2
Laminated Schist		11 $\frac{1}{4}$

This rhythm permits identification of the Upper Striped Schist over wide areas of the Moine Series.

Marker beds have been used by Brown & Engel (1956) in the Adirondacks to divide the formidable 2000-feet thick Grenville Marble into fifteen units with the result that the complex structure of their area can be completely deciphered. Dolomites on different levels in the succession are so alike that they can be separated only by knowing the key-beds between them; such key-beds are a pyritic schist, talcose layers, a fetid graphitic limestone and similar 'kenspeckle' beds.

It is fortunate for the metamorphic geologist that often the operations of metamorphism and migmatization tend to emphasise the individuality of sedimentary beds and to simplify the succession (e.g. Gindy, 1953). One particular bed may thus become a key-bed essential in the interpretation of metamorphic history, especially in regions of polymetamorphism. I may instance the Westing Limestone in the Valla Field Block of Unst in the

Shetlands (Read, 1937). The fixed course of this limestone shows that the metamorphic rocks on one side of it—rocks as diverse as staurolite-kyanite-garnet-gneiss, chloritoid-schist and chlorite-sericite-phyllite—are really three polymetamorphic derivatives of the one pelitic horizon.

I have mentioned correlation, a term that means different things to different classes of geologists. In usual stratigraphy it may mean equivalence in time, a meaning rarely applicable to the kind of correlation made by the metamorphic geologist. He is usually endeavouring to extend a mappable rock-unit, assumed to be indicative of uniform conditions of deposition, over as large an area as possible. His correlation is essentially lithological and his mapping unit is the formation. He can take but little account of diachronous or transgressive formations as his correlation is based on mapping a lithological unit.

Correlation in our sense can be achieved by tracing a direct continuity between the beds concerned, by the use of key-beds, index horizons, some form of rhythm and the like. Local successions may be built up that may be carefully extended by more hazardous correlation into more distant regions. In this, the possibility of marked metamorphic differences in the one formation must be borne in mind and greater emphasis placed on the primary sedimentary characters of the rocks. For instruction in correlation in metamorphic rocks, I commend Balk & Barth's (1936) account of the rocks of Dutchess County, New York. Here the diversity of view is shown to be largely the consequence of the mechanical disturbance of the rocks in one way or another.

The style of the sedimentary, metamorphic and orogenic acts of the drama lead to certain advantages in metamorphic stratigraphy. The primary sedimentary belts are parallel to the orogenic belts and thus many formations continue for remarkable distances along the strike of the fold-belts and show comparatively little lithological change in doing so. As an example, we may cite the Loch Tay Limestone of the Dalradian; in thickness no more than a few hundred feet it extends from Banffshire in Scotland to Donegal in Ireland, a distance of 220 miles. Its correlation over this great interval is based on physical continuity, upon its associated rocks and on the differences in primary sedimentary facies of the rocks above and below it. This extension is as reasonable as anything in metamorphic stratigraphy but farther extension, into Norway for example, is not of the same validity, the reason being that the correlation criteria just cited are not met. Correlations from one fold-belt to another may be of still lower validity; for example, the correlation of a portion of the Upper Dalradian of Scotland with certain metamorphic rocks of Egypt, as has been proposed, can in my opinion be dismissed as a needless guess. There is no particular virtue in correlation for correlation's sake—no one is compelled to correlate.

10. SEDIMENTATION IN MOBILE AND STABLE AREAS

So far, we have been considering for the most part the day-to-day stratigraphical problems that may confront the metamorphic geologist especially in the field. It may be as well to end with a topic of a more general order and to relate our raw materials a little more closely to the crustal drama of which their production is only an act. I do not propose to discuss the validity of the geosynclinal theory in either its classic original or expanded modern forms. It may be that there is a connection to be made between thick geosynclinal fillings, metamorphism, plutonism and orogeny but the consideration of such broad matters awaits the observation and synthesis of a vast amount of data. My humbler aim is concerned with the relation of sedimentary type to the tectonic environment or otherwise of the time of its production.

Modern work on this topic can be said to begin with two fundamental papers of Bailey (1930, 1936). Bailey pointed out that current-bedding and graded bedding are not seen in the same sandstone and these two structures were indeed the hall-marks of two different sandstone facies. Current-bedded rocks were deposited by bottom currents in shallow waters, whereas graded bedding indicated an 'accumulation in deep water to which sedimentary material has penetrated, perhaps as a result of seaquakes' (1930, p. 92). Bailey reminded us of Lapworth's comparison of the Southern Upland greywackes with the Alpine Flysch, which is similarly graded. In his masterly examination of the Welsh Lower Palaeozoic geosyncline, O. T. Jones (1938) later made a detailed comparison of the 'shelly' facies and the 'graptolitic' facies; the former is well sorted, current-bedded and undisturbed, the latter is ill-sorted, with graded bedding and slumped—they are Bailey's two types. A very clear exposition of the contrast in the two sandstone facies is given by Packham (1954); the two facies are genetically distinct, the quartzose sandstone type deposited by traction-currents in shallow water and the greywacke type deposited by turbidity currents in deep water. The two facies involved in these and many other accounts are inherent in the summary descriptions of primary sediments that I have given on an early page of these remarks—they are the oligomict and polymict sediments.

As we have seen, these two types have been tied up with two different environments, the shallow epicontinental seas and the deep seas of the subsidence areas. In terms of tectonics, these two environments have been called the stable shelves and the mobile geosynclines. From this nomenclature there has developed an opinion that there are two definite lithological facies, one of the shelves and one of the geosynclines. This opinion seems to me to be worth examining.

So far as the platform or shelf deposits are concerned, there appears to be a definite sedimentary facies, the current-bedded, 'shelly', orthoquartz-

itic, oligomict facies, with well-differentiated rock-types such as limestones, sandstone and shales, and providing abundant evidence of reworking in shallow seas. Sedimentation in the geosynclines seems to me not to be of a comparable uniform pattern; geosynclines appear to be filled with both kinds of sediments, orthoquartzite and greywacke alike—there is no geosynclinal facies but only a geosyncline-filling. But this statement may need a qualification as there may be a time-preference for the two facies, orthoquartzite early and greywacke late. In the Dalradian, for example, the lower half, below the Loch Tay Limestone, is of orthoquartzite facies, the upper half of greywacke facies. A similar general sequence is found in the Appalachian geosyncline and we may recall Lapworth's comparison of the Alpine Flysch with Southern Upland greywackes. With this time-preference there may likely be a place-preference, the locus of sedimentation becoming displaced towards the border of the chain. Sutton & Watson (1955) have suggested something of the kind for the Dalradian and Moine sedimentation of the Northern Grampians.

We have seen that greywackes are deep-water sediments deposited by turbidity currents set in motion on the margins of submarine slopes. They are therefore an index of instability and their formation indicates the beginning of the end of the filling of the geosyncline and the start of the uprising of cordilleras and the like. They are tectonic sediments and accordingly take their appropriate place in the orogenic drama. I cannot resist pointing out that greywackes are soda-rich sediments characterised by oligoclase, which is the dominant component of the autochthonous, migmatitic, granitisation complexes accompanying the impression of true regional metamorphism. In other words, their formation is later than the early terms of the Granite Series (Read, 1957), as it ought to be. On this self-congratulatory note, I hasten to end.

REFERENCES

- BAILEY, E. B. 1930. New light on Sedimentation and Tectonics. *Geol. Mag.*, **67**, 77.
 ———. 1936. Sedimentation in Relation to Tectonics. *Bull. geol. Soc. Amer.*, **47**, 1713.
 BALK, R. & T. F. W. BARTH. 1936. Structural and Petrologic studies in Dutchess County, New York. *Bull. geol. Soc. Amer.*, **47**, 685, 775.
 BASTIN, E. S. 1909. Chemical Composition as a Criterion in Identifying Metamorphosed Sediments. *J. Geol.*, **17**, 445.
 BROWN, J. S. & A. E. J. ENGEL. 1956. Revision of Grenville Stratigraphy and Structure in the Balmat-Edwards District, North-west Adirondacks. *Bull. geol. Soc. Amer.*, **67**, 1599.
 CHENG, Y. C. 1944. The Migmatites around Bettyhill, Sutherland. *Quart. J. geol. Soc. Lond.*, **99** (for 1943), 107.
 CLOOS, E. 1947. Oolite Deformation in the South Mountain Fold, Maryland. *Bull. geol. Soc. Amer.*, **58**, 843.
 DARWIN, C. 1846. *Geological Observations on South America*.
 ESKOLA, P. E. 1932. Conditions during the Earliest Geological Times as indicated by the Archaean rocks. *Ann. Acad. Sci. Fennicae*, Ser. A, **36**, No. 4.

- ESKOLA, P. E. 1949. The Problem of Mantled Gneiss Domes. *Quart. J. geol. Soc. Lond.*, **104**, 461.
- . 1952. A Discussion of Domes and Granites and Ores. *C.R. Soc. géol. Finlande*, No. 25, 125.
- . 1953. Die Bothnische Formation im Finnischen Grundgebirge. *Geol. Rdsch.*, **41**, 11.
- FLINN, D. 1956. On the Deformation of the Funzie Conglomerate, Fetlar, Shetland. *J. Geol.*, **64**, 480.
- GILLOTT, J. E. 1956. Breccias in the Manx Slates; Their Origin and Stratigraphic Relations. *Liv. & Manch. Geol. Jour.*, **1**, 370.
- GINDY, A. R. 1953. The Plutonic History of the District around Trawenagh Bay, Co. Donegal. *Quart. J. geol. Soc. Lond.*, **108**, 377.
- INGERSON, E. 1940. Fabric Criteria for Distinguishing Pseudo Ripple Marks from Ripple Marks. *Bull. geol. Soc. Amer.*, **51**, 557.
- JONES, O. T. 1938. On the Evolution of a Geosyncline. *Quart. J. geol. Soc. Lond.*, **94**, 1x.
- KUENEN, P. H. & C. I. MIGLIORINI, 1950. Turbidity Currents as a Cause of Graded Bedding. *J. Geol.*, **58**, 91.
- LEHMANN, J. 1884. *Untersuchungen über die Entstehung der altkristallinen Schiefergesteine im sächsischen Granulitgebirge*. Bonn.
- LYELL, C. 1833. *Principles of Geology*. 1st edition, 3.
- NEWELL, N. D. 1957. Supposed Permian Tillites in Northern Mexico are Submarine Slide Deposits. *Bull. geol. Soc. Amer.*, **68**, 1569.
- NIGGLI, P. 1946. Die leukogranitischen, trondhjemitischen und leukosyenit-granitischen Magmen und die Anatexis. *Schweiz. min. petrogr. Mitt.*, **26**, 44.
- PACKHAM, G. H. 1954. Sedimentary Structures as an Important Factor in the Classification of Sandstones. *Amer. J. Sci.*, **252**, 466.
- PETTIJOHN, F. J. 1930. Imbricate Arrangement of Pebbles in a Pre-Cambrian Conglomerate. *J. Geol.*, **38**, 568.
- . 1943. Archaean Sedimentation. *Bull. geol. Soc. Amer.*, **54**, 925.
- . 1949. *Sedimentary Rocks*. New York.
- . 1957. Paleocurrents of Lake Superior Precambrian Quartzites. *Bull. geol. Soc. Amer.*, **68**, 469.
- PITCHER, W. S. & R. C. SINHA. 1958. The Petrochemistry of the Ardara Aureole. *Quart. J. geol. Soc. Lond.*, **113** (for 1957), 393.
- POLDERVAART, A. 1955. Chemistry of the Earth's Crust. *Special Paper No. 62*, Geol. Soc. Amer., 119.
- POTTER, P. E. & R. SIEVER, 1956. Sources of Basal Pennsylvanian Sediments in the Eastern Interior Basin. *J. Geol.*, **64**, 225.
- READ, H. H. 1923. The Geology of Banff, Huntly and Turriff. *Mem. geol. Surv. U.K.*
- . 1936. The Stratigraphical Order of the Dalradian Rocks of the Banffshire Coast. *Geol. Mag.*, **73**, 468.
- . 1937. Metamorphic Correlation in the Polymetamorphic Rocks of the Valla Field Block, Unst, Shetland Islands. *Proc. roy. Soc. Edinb.*, **59**, 195.
- . 1957. *The Granite Controversy*. London.
- REICHE, P. L. 1938. An Analysis of Cross-lamination: the Coconino Sandstone. *J. Geol.*, **46**, 905.
- RICHEY, J. E. & W. Q. KENNEDY, 1939. The Moine and Sub-Moine Series of Morar, Inverness-shire. *Bull. geol. Surv. G.B.* No. 2, 26.
- SCHMIDT, W. 1932. *Tektonik und Verformungslehre*. Berlin.
- SEDERHOLM, J. J. 1897. Über eine archaische Sedimentformation im südwestlichen Finland etc. *Bull. Com. géol. Finl.*, **6**.
- SHOTTON, F. W. 1937. The Lower Bunter Sandstones of North Worcestershire and East Shropshire. *Geol. Mag.*, **74**, 534.
- . 1956. Some Aspects of the New Red Desert in Britain. *Liv. & Manch. Geol. Jour.*, **1**, 450.
- SUTTON, J. & J. WATSON, 1955. The Deposition of the Upper Dalradian Rocks of the Banffshire Coast. *Proc. Geol. Ass., Lond.*, **66**, 101.
- TANTON, T. L. 1930. Determination of Age-relations in Folded Rocks. *Geol. Mag.*, **67**, 73.

- VOGT, T. 1930. On the Chronological Order of Deposition of the Highland Schists. *Geol. Mag.*, **67**, 69.
- WENK, E. 1937. Zur Genese der Bandergneise von Ornö Huvud. *Bull. geol. Inst. Upsala*, **26**, 53.
- WILSON, G., J. SUTTON & J. WATSON, 1953. Current-bedding in the Moine Series of North-Western Scotland. *Geol. Mag.*, **90**, 377.
- ZINGG, T. 1935. Beitrag zur Schotteranalyse. *Schweiz. min. petrogr. Mitt.*, **15**, 39.

The Glacial Deposits around Hertford

by K. M. CLAYTON and JOYCE C. BROWN

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ABSTRACT: A number of sections in the drift deposits around Hertford are described and a local stratigraphical succession is established. The deposits are shown to have accumulated in an extensive pro-glacial lake formed when the former valley of the River Thames was blocked by an ice-sheet. The recognition of this lake solves the problem of the anomalous gradient of the Winter Hill Terrace and confirms that the River Thames was diverted from the Finchley depression by the last ice-sheet to reach as far south as the London Basin.

1. THE STRATIGRAPHY OF THE DEPOSITS

(a) Introduction

The glacial deposits in the vicinity of Hertford have not been described in detail since the publication, in 1924, of the Memoir by Sherlock & Pocock following the geological resurvey of the Hertford sheet. Recent workings for sand and gravel have added to the exposures in the area, and show a complicated series of deposits. Their stratigraphy is of significance in the elucidation of Pleistocene history, not only of the immediate area, but of the London Basin as a whole. Most of the exposures to be described lie within a few miles of Hertford on the sides of the valleys of the Lea and its tributaries, the Beane and the Rib. No single exposure reveals the complete series of deposits, but the workings are sufficiently numerous for a general stratigraphy to be established.

The most complete range of deposits is visible in the large disused pit west of Ware cemetery, on the north side of the Lea Valley. The sections

exposed in this pit have attracted the attention of previous workers, notably Sherlock, and several descriptions of them have been published (Sherlock, 1915a; Barrow, 1918; Sherlock & Pocock, 1924). There are still clean faces visible, revealing the following composite section.

SECTION A.¹ Pit west of Ware cemetery (52/345149. Surface c. 220 feet O.D.)

	feet
3. Chalky boulder clay, weathered light brown, resting on un-weathered blue chalky boulder clay (seen at the north end of the pit)	up to 20
2. Fine bedded chalky sand and gravel with some beds of coarse gravel (seen at the north end of the pit)... ..	up to 10
1. Lacustrine deposits and chalky boulder clay in close association (seen in a trial hole at the north end of the pit and in a face on the east side)	30-40
Resting on Chalk, rising in pinnacles and ridges from the floor of the pit.	

Sherlock established a more comprehensive succession for the drifts near Ware, using evidence from pits now overgrown. As originally published (Sherlock, 1915) the succession was as given in the table below, but in later publications (Sherlock, 1920; Sherlock & Pocock, 1924) it was somewhat modified by suggesting that Beds 1 and 3 were identical.

6. Chalky boulder clay
5. Sand and gravel in lenticles
4. Laminated clays
3. Chalky boulder clay in lenticles, always thin
2. The main mass of bedded sand and gravel
1. Tough chalky boulder clay with lenticles of gravel, etc.
Chalk.

It was emphasised by both Barrow (1918) and Sherlock (1915) that all the beds were not visible in any one section, nor, indeed, in any one pit. However, correlation between Sherlock's succession and that given in Section A is facilitated by the fact that the chalky boulder clay seen today to cap the deposits (Section A, Bed 3) is undoubtedly the uppermost boulder clay (6) of Sherlock's succession. Thus the chalky sand and gravel (Section A, 2) is Sherlock's sand and gravel in lenticles (5), and the complex of lacustrine deposits and boulder clay (Section A, 1) is the equivalent of Sherlock's laminated clays and lenticles of chalky boulder clay (Beds 3 and 4). The lenticular nature of this boulder clay is demonstrated by its absence from the face at the south side of the pit, where about nine feet of bedded fine sand, silt and silty clay overlie sharply alternating beds of gravel and sand. This bedded deposit is probably what Sherlock describes as the 'main mass of bedded sand and gravel' (Bed 2).

¹ The sections described are shown in Fig. 1.

The authors have not seen an exposure of the lowest deposit recorded by Sherlock, the tough chalky boulder clay (1). It is described (Sherlock & Pocock, 1924) as a 'chalky clay, darker than usual owing to a large amount of black shale, probably Kimmeridge Clay, with abundant broken shells'. Barrow (1918) stresses its toughness, and says that it has 'an extremely uneven top, which seems to have been ploughed and afterwards very unevenly eroded (channelled) when the bedded gravels were being first laid down'. It has already been noted (Section A) that the surface of the chalk in the floor of the pit is very uneven and it is suggested that the irregular surface upon which the later deposits rest is probably the result of perma-

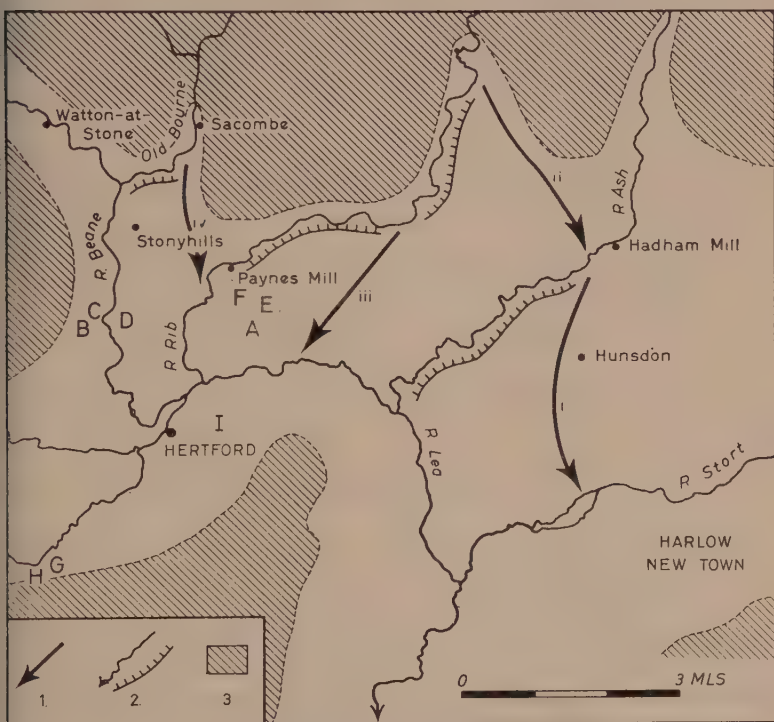


Fig. 1. Stream pattern of the Hertford area

- Key: 1. Drift filled valley or spillway
 (i) Lower Rib-Ash valley
 (ii) Rib valley
 (iii) Little Farnham's Hall spillway
 (iv) Old Bourne valley.
 2. Valley initiated at ice-margin.
 3. Land rising above the lake deposits.

The letters indicate the positions of the sections in the deposits listed in the text.

frost action. There is evidence for this in a great inverted wedge of unbedded gravel, interrupting the bedding of the sand and gravel into which it rises, which overlies one of the pinnacles of chalk at the south end of the pit. The impersistent character of this lower boulder clay is implicit in the Memoir (Sherlock & Pocock, 1924) and Barrow (1918) asserts that it 'is known to be absent from all the other pits in the Lea Valley'. Its provenance will be discussed below.

The uppermost boulder clay in the Ware pit (Section A, 3) is far more extensive. It is the most recent of the true glacial deposits of the area. Where it caps the high ground north of the Lea, it rests directly on the Chalk, but with the fall in the sub-glacial surface towards the Lea Valley it comes to rest on gravels, as in Section A. Subsequent erosion has stripped this upper till from the gravels near the margins of the present valleys, so that it is seldom seen in section. Another clear exposure of this till is, however, visible in a new pit west of the Beane Valley at Waterford, where the following section is seen.

SECTION B. New pit, west of the Beane Valley, Waterford (52/305150. Surface 248 feet O.D.)

	feet
4. Chalky boulder clay, weathered at surface	8
3. Sand and gravel, becoming finer with current bedding towards the base	12-15
2. Laminated silt and clay with lenticles of chalky boulder clay...	9
1. Fine bedded sand and gravel, base not seen	2

Another pit, now disused, has been excavated lower on the valley side, about 300 yards to the east, and enables the succession to be extended into lower beds.

SECTION C. Disused pit, west of the Beane, Waterford (52/308152. Surface c. 225 feet O.D.)

	feet
4. A lenticular bed of brown-grey chalky boulder clay	up to 6
3. Fine laminated sand	1
2. Stratified gravel	about 15
1. Blue-grey chalky boulder clay forming the floor of the pit, base not seen	5

It is suggested that the lenticular chalky boulder clay (Bed 2 of Section B and 4 of Section C) is the same deposit, a suggestion based both on its lithological character and on the fact that the two beds occur at the same height. If this correlation is correct, then there are here, as at Ware, three main boulder clays. Confirmatory evidence is afforded by the succession seen in the pits on the opposite, eastern, side of the Beane Valley. These pits do not expose the upper till, the highest beds being the underlying gravel, but a small patch of the upper till occurs a little way to the south, above the Molewood railway tunnel (320140).

SECTION D. Pit east of the Beane Valley, Waterford (52/317148. Surface c. 220 feet O.D.)

(Upper till not exposed)								feet
7. Bedded gravel	...	...	...	...	...	...	...	2
6. Chalky boulder clay	...	...	...	...	...	...	...	2
5. Laminated silt or fine sand	...	...	...	...	...	...	...	2
4. Bedded gravel	...	...	...	...	...	...	...	5
3. Fine white sand and gravel (obscured)	...	...	...	...	...	...	...	10
2. Chalky boulder clay	...	...	...	...	...	...	...	1½
1. Horizontally and current-bedded sand and gravel, base not seen								15-18

Here again there are three boulder clays. It is suggested that the lowest boulder clay here (Section D, 2) is the equivalent of the lowest till on the west side of the valley (Section C, 1) and that the higher boulder clay in this eastern pit may be correlated with the lenticular boulder clays exposed on the west side of the valley (i.e. Section D, 6 is equivalent to B, 2 and to C, 4). It will be noticed that in all these sections the middle boulder clay occurs in close association with lacustrine deposits. This association has already been noted at Ware (Section A, 1) and affords support for the correlations suggested for the Waterford pits. That the upper till, capping the interfluvies, is part of the same spread is evident on morphological grounds.

The succession at all the exposures discussed in this introductory section may be summarised as follows:

6. Upper till—chalky boulder clay
5. Bedded sands and gravels
4. Middle till complex—chalky boulder clay, lacustrine sediments and some gravel
3. Bedded sands and gravels
2. Lower till—chalky boulder clay in one or more bands, separated by gravel but unassociated with lake silts
1. Bedded sands and gravels

Beds 1 and 2 occur in restricted areas only and are frequently absent.

(b) The Lower Till and Associated Gravels

Discussion of these discontinuous beds is made difficult by the very few exposures. The boulder clay is seen to occur in one or more bands, everywhere lying at relatively low altitudes within the valleys. Thus in Sections C and D, this lowest till occurs at about 200 feet O.D., while in Brazier's pit, Hertford (52/336127, see Appendix for section details), it lies at only 170 feet O.D. Lithologically it is dark blue in colour and tough in consistency. All the known occurrences are within the Beane Valley, except for the Hertford pit which lies opposite the Beane confluence with the Lea. This suggests that the till was brought by an ice-lobe through the Stevenage gap and down the Beane Valley. This seems to be confirmed by the orientation of 295° given by till fabric analysis for the lowest boulder clay at

Waterford (Section C, 1). Farther to the east, at Harlow, a similar boulder clay underlies gravels associated with lake silts, and may well represent the same early advance (Clayton, 1957). At Harlow it tends to be darker in colour than the upper till, and early descriptions referred to it as a blue boulder clay and named it the Harlow boulder clay (Irving, 1913).

(c) The Middle Till Complex

The close association of bands of boulder clay with the finer lake deposits, the clays, silts and fine sands, has already been noticed. It remains to demonstrate the remarkable local variations found in this complex. In general, the lake sediments are fairly constant over the whole area, and in many sections amount to as much as nine to twelve feet of fine material clearly accumulated in still water. The complexities seem to be due to the very inconstant beds of boulder clay which in some pits divide these still water sediments into a number of separate beds.

In the pit at Ware which has already been described (Section A) the complex includes up to four bands of chalky boulder clay, which from the section on the east side of the pit are seen to lie towards the top of the lake sediments. In one place there are twenty feet of lacustrine sediments below the middle boulder clay. It is impossible to trace any of the bands of boulder clay for any distance, for both they and the interleaved silts die out and replace each other in an extremely intricate manner. In places, indeed, the boulder clays may be completely missing. Thus only 400 yards north of the section in the Ware pit which showed four bands of boulder clay, a trial pit, thirty feet deep, showed lacustrine sediments with no boulder clay beds at all.

SECTION E. Trial Hole, Watton Road, Ware (52/346153. Surface c. 220 feet O.D.)

	feet
5. Coarse gravel, poorly sorted	4
4. Laminated and current-bedded fine sand and silt	12
3. Bedded gravels	4
2. Loam and silty sand, laminated	4
1. Coarse gravel, base not seen	6

Less than three-quarters of a mile to the north-west there is a further pit in the same beds, this time showing only one band of the middle boulder clay.

SECTION F. Brazier's Pit, Payne's Mill (52/340160. Surface c. 245 feet O.D.)

(Upper till not exposed)	feet
4. Very well sorted and bedded sand and gravel	20-25
3. Blue-grey chalky boulder clay	up to 5
2. Current-bedded sand and gravel	15-20
1. Laminated silt	6-8
Chalk	

The sections in this till-silt complex exposed in the Beane Valley at Waterford have already been discussed (Sections B, C, D). Further up the valley at Stonyhills (Fig. 1), laminated clay ('brickearth') occurs over a wide enough area to be shown on the published map, and Sherlock records the section exposed at the brick-works (52/320172) in the Memoir. The section is still visible, but shows no other beds, the whole of the fifteen feet of face being cut in a fine, silty clay. However, a new pit is being opened to the south-west (52/318168) and shows that the brickearth is underlain first by chalky boulder clay, and then by bedded gravel containing a thin band of laminated silt. From the field relationship of the two pits it seems that the main, upper silt or brickearth is overlain first by sands and gravels and then by the upper till, which caps the slope to the east at about 235 feet O.D., near Dimmings (52/326167). The sequence of deposits here is almost identical with that in the upper part of Section D (east side of the Beane Valley, Waterford), except that at Stonyhills the middle boulder clay underlies the silt, while at Waterford this sequence is reversed.

Two further sections, just over a quarter of a mile apart in the Lea Valley, also show these rapid changes within the middle till complex. A part of the first section was recorded by Sherlock in the Memoir and probably refers to Beds 5-7 of the present section.

SECTION G. Pit 400 yards east of Water Hall (52/301097. Surface *c.* 200 feet O.D.)

	feet
7. Chalky boulder clay	7-8
6. Well sorted and bedded sand and gravel with some laminated sand	3
5. Chalky boulder clay	up to 7
4. Fine laminated sand (represented in places by 6 inches of silt)	1
3. Well sorted and bedded sand and gravel	6
2. Silt	2½
1. Sand and gravel, base not seen	1

Bed 7 in this pit is clearly the upper till of the area, so that the middle till complex is represented by Beds 2-5. The other pit has a more complex succession with three separate beds of till in the lacustrine-till association.

SECTION H. Pit 300 yards south of Water Hall (52/298094. Surface *c.* 210 feet O.D.)

(Upper till and gravel not exposed)		feet
7. Chalky boulder clay	up to 7	
6. Silt	1	
5. Chalky boulder clay	5	
4. Silt	3	
3. Chalky boulder clay	4	
2. Gravel, with one foot bands of silt	up to 15	
1. Gravel, no silt	12-15	
Chalk		

The middle till appears to have been deposited by a fluctuating ice-margin, extending into the lake in a series of lobes. The most important of these, in the case of the sections described here, seems to have extended down the Beane Valley, thus the middle till at Waterford (Section C, 4) has an orientation between 300° (West & Donner, 1956) and 320° (determination by authors). However, there is evidence that a lobe also entered the area from the east, although this depends on the section at Brazier's pit, Hertford, an unsatisfactory exposure which is discussed in the Appendix.

(d) The Upper Till and Underlying Gravels

The base of the upper till lies at 240 feet west of Waterford (Section B, 4) but this height is exceptional, for the upper till comes on above the upper gravels most commonly at 200–230 feet. Thus in the Ware pit (Section A, 3) the base is at 200 feet O.D. Where the till itself is absent, the upper surface of the gravels lies within the same range of height. When viewed from higher ground this even surface of drift, the 'Lower Plain' of McKenney Hughes (1868), appears to be almost horizontal, and it forms a striking element in the local topography.

The gravels beneath the upper till are generally fine and well bedded, tending to become finer towards the base. They thus represent a transition from the fine lake sediments to gravels deposited by melt-water streams. The overlying upper till is a typical chalky boulder clay, although in places it has a rather low proportion of stones other than pebbles of chalk. The direction from which this till came has been investigated by fabric analysis and shows that the lake sediments were finally overrun by an ice-sheet from the north-east. Thus the upper till at Waterford (Section B, 4) gave an orientation of 55° . West & Donner quote orientations from exposures of this till within the main part of the Vale of St. Albans; they range between 35° and 40° degrees.

(e) Depositional History

It has been implicit in the discussion of these sections that the complex of boulder clay and lacustrine sediments is of the same age wherever it occurs. This assumption may be justified on the ground that the accumulation of considerable thicknesses of laminated silt and clay must have taken place very slowly in still water and have occupied a significant proportion of the total time needed for the deposition of all the glacial deposits of the area. Further, the interdigitation of boulder clay and silt, and occasionally gravel, indicates that they are really facies of one period in the depositional history. Such a range of deposits can only have accumulated in a proglacial lake, invaded from time to time by lobes of the impounding ice-sheet. The continuity of the remaining beds, although perhaps less easy to establish, seems in little doubt. In none of the many excellent sections

exposed in the area is there any sign of a prolonged break in deposition. The beds, despite changes in lithology, succeed each other without any break in time. The lower till and the upper till seem to be the deposits of first and last advances of an ice-sheet during a complex glaciation.

The maximum extent of this pro-glacial lake was considerable. Lacustrine deposits are known from a wide area (Fig. 2). In the Stort Valley a very fine chalky sand is exposed in a pit at Netteswell (52/452108) and many of the boreholes put down at Harlow New Town passed through beds of fine silt and running sand. In the Ash Valley, a pit at Hadham Towers (52/431173) reveals thirteen feet of silts and fine sands with a variable band of fine chalky gravel, lying within the gravels. South-west of Hoddesdon, in the Lea Valley, laminated silty sand overlies a boulder clay within the gravels (52/361079). In the Mimram Valley temporary sections have revealed brickearth in close association with boulder clay (not the upper till) and laminated clay is known to occur as far west as Welwyn (52/234158). North of Watton-at-Stone a pit is cut through part of the lake margin (52/291211) for it shows the fore-set beds of a gravel delta overlain by laminated silt and fine sand. It is likely that the lake also extended to the south, into the Finchley depression, but there are now very few sections in this area.

Although the extent of the lake is considerable, it will be seen that the best exposures in the sediments are concentrated around the town of Hertford (Fig. 2). For this reason it seems best that the lake should be called Lake Hertford.

2. THE CHRONOLOGICAL POSITION OF LAKE HERTFORD

In attempting to determine the time at which this lake was formed and the circumstances under which the water was impounded, the most direct line of investigation concerns the uppermost boulder clay. As has already been indicated this clay is neither particularly thick nor well exposed in the Hertford area, but its position on all the main interfluves shows that it is part of the main sheet of boulder clay found to the east and the north. This correlation is quite straightforward, but unfortunately there is no unanimity of view about the age of the main sheet of boulder clay. West & Donner (1956), using the criterion of till orientation, have correlated some of the boulder clays of this area with those of East Anglia, but their suggested division of the deposits does not agree with the evidence already discussed that the deposits were accumulated in one complex glaciation. A correlation with the London Basin would in any case be of more value.

Professor Wooldridge (1938; Wooldridge & Linton, 1955) has established that two distinct ice-sheets reached the area north of London, and he has related them to the evolution of the River Thames. He has shown that

the Thames formerly flowed north of its present position, first along the line of the Vale of St. Albans, whence it was diverted by the early Chiltern ice-sheet, and then by a route further south known as the Middlesex loopway. This route took the Thames past Finchley, north of the Hampstead ridge, from where it flowed north-eastwards to rejoin the line of its former course near Hoddesdon. Both before and after the Chiltern glaciation, the Thames continued eastwards across central Essex towards Chelmsford, following a valley now deeply buried in drift, and known as the mid-Essex depression (Wooldridge & Henderson, 1955). The second ice-sheet to reach the London Basin, often known as the Great Eastern, diverted the Thames to its present course through London.

The terraces of the River Thames, well preserved north-west and west of London, have been related to this sequence of courses (Wooldridge & Linton, 1955). It has been shown that the Thames flowed by the Middlesex loopway through the Finchley depression from the time when it deposited the Higher Gravel Train at a little below 300 feet north-west of London, until the formation of the Winter Hill Terrace (250 feet west of London).

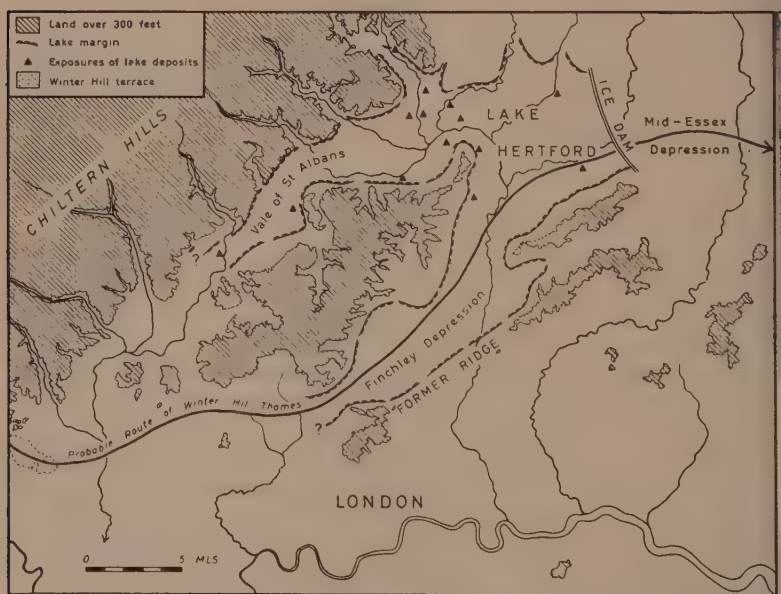


Fig. 2. The maximum extent of Lake Hertford

Note: Those parts of the Springfield Till that rise above 300 ft. O.D. have not been shaded.

(Hare, 1947). The next terrace in the sequence, the Black Park, leads south-eastwards towards the present valley, and appears to mark the line of the river after the diversion from the Finchley route; it occurs at 175–180 feet in south-west London. All the lower and younger terraces of the Thames are found within the present valley through London.

The diversion of the Thames from the Middlesex loopway was caused by the ice-sheet advancing westwards into the valley and depositing the chalky boulder clay which occurs as far west as Finchley. Another lobe of the same ice-sheet advanced westwards into the Vale of St. Albans and laid down similar deposits there. From field and map evidence it is clear that the upper chalky boulder clay of Finchley and the Vale of St. Albans is the upper boulder clay of the Hertford deposits. As the term Great Eastern is not free of ambiguity, this boulder clay will be referred to as the Springfield Till, a name recently adopted for this deposit in Essex (Clayton, 1957). Resurvey of part of the Essex drifts has shown that this is the youngest boulder clay found within the London Basin. It was laid down by the final advance of an ice-sheet which is already known to have an early advance represented by the Maldon Till, while marl bands in the intervening gravels suggest other fluctuations.

Thus the Thames, flowing along the Middlesex loopway and through the mid-Essex depression, was blocked by the advance of the last ice-sheet to reach the London Basin. It is probable that the lake was impounded in more than one stage as this glaciation was a complex one, but at present there is no clear evidence on this point. The impounded water stretched westwards into the Finchley depression, and also up the valleys of the tributary rivers, including the streams draining the Vale of St. Albans and joining the Thames below Ware. Later erosion has destroyed most of the evidence of the sequence of events in the Middlesex loopway, apart from the crescentic barrier of boulder clay still blocking the former valley at Finchley. Between this boulder clay and the River Colne, few remnants of the river terraces have survived erosion, the same is true of the glacial deposits between Finchley and the River Lea. The erosion has been much less severe further to the north, and in the Vale of St. Albans (Evans, 1954) and the upper Lea Valley the lake deposits are well preserved.

The existence of lake deposits beneath the Springfield Till has long been known, as will be clear from the many published references to the sections described in the first part of this paper. In every case these were regarded as local occurrences, and only Sherlock (1924) attempted to reconstruct the circumstances under which they accumulated. He postulated ponding north and west of Ware, but as has already been shown, lake deposits are more widespread than this and it is clear that Sherlock under-estimated the extent of the lake. The recognition that the many recorded instances of lake deposits beneath the Springfield Till were formed in the same lake—at

varying stages of its growth and decay—makes possible a considerable advance in the glacial history of the River Thames.

It seems likely that the advancing ice reached the Thames Valley soon after the deposition of the Harefield Terrace (Lower Gravel Train). The lake was impounded in the Thames Valley and the deposits rest on a surface that is the valley system of the river at that time. The Harefield Terrace occurs at 285 feet at Harefield, and by extending its longitudinal gradient eastwards, Professor Wooldridge (Wooldridge & Linton, 1955) suggested that it had fallen to about 170 feet at Broxbourne. The boreholes put down at Harlow New Town show a wide flat cut on the London Clay at about 165 feet, and this seems to confirm the estimate (Clayton, 1957). However, the deposits of the succeeding glaciation descend below this Harefield Terrace level along the main valleys, and it seems that with the fall of sea-level accompanying the advance of the ice-sheet, the Thames system was rejuvenated, perhaps by as much as forty feet, before the ice reached it. The deposits described from the Hertford area rest on solid rocks at heights down to about 135–150 feet, confirming this reconstruction of the form of the lake floor.

The invasion of the Hertford arm of the lake by ice-lobes both from the east and north-west, meant that a very large amount of material was deposited, either as till or as water-borne material. The quantity of sediment seems to have been enough to fill the lake completely, for when the Springfield Till ice over rode the deposits, it did so on an even surface of gravels that concealed the irregularities of the lake floor. By that stage the Hertford arm, at least, had been converted to land.

The surface of the lake before the final advance of the Springfield ice-sheet seems to have been between 220 and 240 feet. This figure is based on the level to which the lake was filled in with gravel by the braided streams which entered it, but it is supported by the frequent occurrence of lake silts at about 200 feet O.D. The highest silts are found in the pit on the west side of the Beane Valley at Waterford, where they lie at 225 feet (52/305150). This water-level must have been related to the height of the overflow or overflows draining the lake; unfortunately the great changes that have occurred in the topography of the London area, following the diversion of the River Thames from the Middlesex loopway, make recognition of the overflows that functioned most improbable.

3. THE MORPHOLOGY OF THE AREA AFFECTED BY LAKE HERTFORD

The recognition of this extensive pro-glacial lake is of assistance in the understanding of the morphological features of the area. At this stage only the more important instances can be mentioned, and three separate examples will be described here.

(a) The Origin of the Lower Lea Valley

Before the Thames was diverted to its present valley its course led eastwards through the mid-Essex depression. Thus at that time the Lower Lea Valley did not exist. Some support for this deduction has been found in the generally relatively high level of the glacial deposits on the sides of the valley (Wells & Wooldridge, 1923). Lake Hertford was impounded by ice blocking the mid-Essex depression, and its southern shore must have been formed by the side of the valley from the Finchley depression through to the ice barrier. This former valley edge is today deeply broken by the River Lea where it flows between the Epping Forest and Hampstead ridges to reach the Thames (Fig. 2). These ridges must have formed a continuous barrier when the lake existed. It is apparent that a depression existed to the south, into which the Thames was diverted by the Springfield ice, and it was only after this diversion that a stream cut back northwards through the ridge to initiate the present River Lea.

(b) The River Pattern of the Hertford Area

The infilling of Lake Hertford served virtually to obliterate the lower parts of the valleys draining into the Vale of St. Albans. When the Springfield ice-sheet advanced from the east the streams were meandering freely over the even surface of the lake deposits, well above their former valley floors. As the ice-front moved westwards across the mouths of successive tributary valleys, the streams issuing from them were diverted into ice-marginal courses, some of which became sufficiently well established to remain as part of the post-glacial drainage pattern. Professor Wooldridge (1953) has demonstrated such a series of ice-marginal drainage diversions in the western part of the Vale of St. Albans, and one of the authors has traced, beneath the drift, the former lower courses of the streams entering the Vale near Hertford.

The buried valleys are shown on the map (Fig. 1). It will be seen that above Hadham Mill the Ash follows its pre-glacial valley. Near this point the pre-glacial stream received a tributary from the north-west, whose drift-filled valley (ii of Fig. 1) can be traced upstream into the present Rib Valley at Standon. From Hadham Mill the combined waters of the two streams flowed south to join the Thames of the Harefield Terrace stage south of Hunsdon. This drainage was diverted westwards along the advancing margin of the Springfield ice to initiate the present course of the lower Ash. This itself was overrun by the ice and the Rib (for the Ash no longer existed) was diverted into a course between the ice-front and the rising ground to the north. It escaped by a temporary channel (iii), now filled with drift, beneath Little Farnham's Hall, Ware. Later still it was diverted to its present lower valley, whose course strongly suggests its origin round

the margin of an ice-lobe. However, the lowest north-south reach of the present Rib, below Payne's Mill, appears to coincide with a pre-glacial valley. There is evidence to suggest that this valley was occupied by a stream heading northwards in the system of valleys above Sacombe drained by the Old Bourne. As the Rib was diverted westward into the lower section of this valley, so, further upstream, the Old Bourne was diverted westwards into the Beane below Watton-at-Stone.

It is not entirely clear which of the ice-marginal courses developed during the advance and which during the decay of the ice. The Little Farnham's Hall spillway (iii) clearly functioned only before it was overrun by the ice, but it is possible that the establishment of the Rib in its present course was accomplished only as the ice melted. The Beane, below Watton-at-Stone, appears to have suffered no diversion. A considerable valley, excavated in Chalk, may be traced upstream beneath the glacial deposits in which the present valley is cut, towards the windgaps in the Chalk scarp at Hitchin and Stevenage. This valley was in existence before the earliest ice entered the area, for representatives of all three tills lie within it.

(c) The Winter Hill Terrace of the Thames

The existence of Lake Hertford, with a water-level of 220–240 feet, offers a solution to the problem of the Winter Hill Terrace. It has frequently been noticed (Hare, 1947; Sealy, 1956) that while the gradients of most of the terraces of the River Thames are comparable with that of the present river, the Winter Hill Terrace is anomalous. Professor Hare wrote: 'The eastward slope of the terrace is very small; in fact it hardly exists.' More recently, Professor Wooldridge (Wooldridge & Linton, 1955) has shown that by the admittedly crude method of projecting the terrace profiles eastwards, the Harefield Terrace probably fell to about 170 feet near Broxbourne, and it has already been suggested that this figure is of the right order. In contrast, the more recent Winter Hill Terrace would have fallen to only 200–220 feet. This curious relationship, it has been suggested, is the result of the Winter Hill Thames being adjusted to a high sea-level in the First Interglacial period, while the Harefield Terrace is graded to a lower sea-level associated with colder conditions.

The alternative hypothesis that suggests itself is that the Winter Hill Thames flowed into Lake Hertford, and that the Winter Hill Terrace is formed of the material introduced by the Thames and corresponds to the deltaic material introduced by the streams in the Hertford area. The Winter Hill Terrace remnants west of the Colne lie at 257–260 feet; any former extension to the east is now lost by erosion unless the gravel at Wembley (234 feet O.D.) represents this feature. These heights are consistent with the suggested surface level of the lake. Professor Hare, in commenting on the low longitudinal gradient of the Winter Hill Terrace,

was led to suggest that this may have resulted from 'prolonged aggradation in a ponded-up valley', a suggestion that is now seen to be highly probable.

The resulting correlation of the Winter Hill Terrace with the stage before the final advance of the ice-sheet that deposited the Springfield Till is in accordance with the evidence from the Colne Valley. There the outwash from the ice-sheet occupying the Vale of St. Albans can be traced down the valley at almost the same elevation as the Winter Hill Terrace of the Colne (Hare, 1947), and Sherlock (1924) suggested that it was this outwash that had diverted the Thames southward. Both Wooldridge (1938) and Hare (1947) stress this close association of the Winter Hill Terrace and the outwash from the Vale of St. Albans. It is also recognised that the succeeding terrace of the Thames, the Black Park Terrace, marks the adoption by the diverted Thames of its present valley through London.

4. CONCLUSIONS

The sequence of events may now be summarised. At the stage of the Harefield Terrace (Lower Gravel Train) the River Thames flowed by the Middlesex loopway and the mid-Essex depression towards Chelmsford. This valley was blocked by the advance of the last ice-sheet to reach the London Basin, and a considerable pro-glacial lake was formed, with arms stretching up the Vale of St. Albans and into the Finchley depression. This lake, nearly 100 feet deep in places, was largely filled in by material derived from the ice-sheets to the north and east, and from the Thames and its tributaries in the west. The deposits include a thick accumulation of silts and clays, well exposed in the Hertford area, but also a number of beds of boulder clay introduced by fluctuating ice-lobes extending into the lake from the north-east and north-west. The gravel-spreads deposited at the lake margin form flat surfaces, and that formed by the Thames at the western margin of the lake is identified as the Winter Hill Terrace. The lake deposits were eventually overrun by an ice-advance from the north-east which deposited the Springfield Till, found as far west as Watford in the Vale of St. Albans and Finchley in the Middlesex loopway. This ice, with its associated outwash, diverted the River Thames southward to its present course. At about the same time the formerly continuous Epping Forest-Hampstead ridge was breached, and the River Lea initiated.

APPENDIX

Brazier's Pit, Hertford

This section occupies an important place in the published work on the Hertford area, and it is clear that it shows several interesting features in a very complex succession. However, the exposures today are very poor and as they occur at several separate levels, it is not possible to describe the

full sequence with any certainty. For this reason, the section was not included in the general account of the stratigraphy of the area.

The pit lies on the south side of the Lea Valley, and does not expose the upper till, which comes on southwards at about 215 feet O.D. The highest bed actually exposed is the gravel which underlies the upper till. The suggested composite section for the pit is as follows:

SECTION I. Brazier's Pit, Hertford (52/336127. Surface c. 205 feet O.D.)	
(Upper till not exposed)	
5. Bedded sand and gravel; some very fine sand especially towards the base where there is some laminated sand and clay ...	15 seen
4. White chalky boulder clay in lenticles	up to 100
3. Some boulder clay and gravel (not exposed)	? 15
2. One or two rafts of dark blue-grey chalky boulder clay, one fairly persistent, separated by sand, gravel and brickearth ...	c. 12
1. Fine sand and gravel, believed to rest on Chalk at c. 160 feet O.D.	?

Recently West & Donner (1956) obtained two orientations from a bed of boulder clay in this pit, described as '3 m. light brown chalky boulder clay, decalcified to 50 cm., resting on 3 m. dark blue chalky boulder clay'. The orientations were 55° and 310° respectively. The upper till with the northeasterly derivation is probably Bed 4 of the section above, the lower till is not at present exposed and must form part of Bed 3. The dark blue chalky boulder clay actually exposed is Bed 2, and as this lies well below Bed 4 it cannot be West & Donner's lower till. There would thus appear to be at least four tills in this pit.

When Sherlock (Sherlock & Pocock, 1924) and Barrow (1910, 1914) recorded the sections visible in this pit, they did not see such a complex sequence of deposits. Both workers note a bed or lenticle of boulder clay within the gravels. For example, in the Memoir, Sherlock states that 'usually up to twelve feet of sand and gravel lie on a band of boulder clay about fourteen feet thick, which in turn overlies about sixteen feet of sand and gravel. The sand and gravel is interlocked with the clay and a lenticle of it was once observed to lie three feet down in the clay. The lower mass of gravel is more horizontally bedded, more sandy, and of finer grain, than that above the clay.' Barrow (1910) noted that the top and base of the boulder clay were decalcified, the centre remaining dark. It would seem possible, following the work of West & Donner, that the dark centre may have been material brought from a different direction.

The correlation of the deposits in this pit with the general sequence for the Hertford area is not entirely clear. It has already been implied that Beds 3 and 4 may be the equivalent of the middle till complex; as Bed 4, the white chalky boulder clay is overlain by lacustrine sediments, this correlation may be justified. However, nowhere else are two boulder clays of different character known from this middle till complex. If the correlation

is correct, the Brazier's Pit sequence shows that during the formation of the middle till complex the Hertford area was invaded by ice-lobes, not only down the Beane Valley, but also from the north-east. This is, of course, quite a probable state of affairs.

If both Beds 3 and 4 are the equivalent of the middle till complex, then the lowest clay in this pit, Bed 2, is likely to be part of the discontinuous lower till. Sherlock (1920) was clearly unaware of the existence of this till, and stated that the lower sand and gravel rested on chalk. The present exposure of this lower boulder clay is nearer the valley than the sections in the higher deposits and it may well be that this boulder clay occurs only low down within the valley. This has been seen to be true of other occurrences of the lower till and accounts for its patchy distribution.

REFERENCES

- BARROW, G. 1910. Excursion to Hertingfordbury and Hertford. *Proc. Geol. Ass., Lond.*, **21**, 167.
- . 1914. Report of an Excursion to Hertingfordbury and Hertford. *Ibid.*, **25**, 115.
- . 1918. Excursion to Ware. *Ibid.*, **29**, 42.
- CLAYTON, K. M. 1957. Some Aspects of the Glacial Deposits of Essex. *Ibid.*, **68**, 1.
- EVANS, P. 1954. Field Meeting in the Vale of St. Albans. *Ibid.*, **65**, 18.
- HARE, F. K. 1947. The Geomorphology of a Part of the Middle Thames. *Ibid.*, **58**, 294.
- HILL, W. 1914. Report of an Excursion to Knebworth and Hertford. *Ibid.*, **25**, 288.
- HUGHES, T. McK. 1868. On the Two Plains of Hertfordshire and their Gravels. *Quart. J. geol. Soc. Lond.*, **24**, 283.
- IRVING, A. & P. A. 1913. The Harlow Boulder Clay. *Rep. Brit. Ass.*, 480.
- SEALY, K. R. & C. E. 1956. The Terraces of the Middle Thames. *Proc. Geol. Ass., Lond.*, **67**, 369.
- SHERLOCK, R. L. 1915. In *Summ. Progr. geol. Surv., Lond.*, 1914, 31.
- . 1915 a. Excursion to Ware. *Proc. Geol. Ass., Lond.*, **27**, 273.
- . 1920. In *Summ. Progr. geol. Surv., Lond.*, 1919, 7.
- . 1924. On the Superficial Deposits of South Herts and South Bucks. *Proc. Geol. Ass., Lond.*, **35**, 19.
- & R. W. POCOCK. 1924. The Geology of the Country around Hertford. *Mem. geol. Surv. U.K.*
- WELLS, A. K. & S. W. WOOLDRIDGE. 1923. Notes on the Geology of Epping Forest. *Proc. Geol. Ass., Lond.*, **34**, 244.
- WEST, R. G. & J. J. DONNER. 1956. The Glaciations of East Anglia and the Midlands. *Quart. J. geol. Soc. Lond.*, **112**, 69.
- WOOLDRIDGE, S. W. 1938. The Glaciation of the London Basin. *Ibid.*, **94**, 627.
- . 1953. Some Marginal Drainage Features of the Chalky Boulder Clay Ice-sheet in Hertfordshire. *Proc. Geol. Ass., Lond.*, **64**, 208.
- & H. C. K. HENDERSON. 1955. Some Aspects of the Physiography of the Eastern Part of the London Basin. *Inst. Brit. Geog.*, **21**, 19.
- & D. L. LINTON. 1955. *Structure, Surface and Drainage in South-east England.*

Further Observations on a Quaternary Deposit at Bowleaze Cove, near Weymouth, Dorset

by the late A. G. DAVIS; and J. N. CARRECK

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ABSTRACT: Some new faunal records for the Early Holocene Loam of Bowleaze Cove, described by the authors in 1955, are listed, together with new molluscan records from the Holocene tufa of Blashenwell, Dorset, with which the Bowleaze deposit has been compared and contrasted. Conclusions are drawn, confirming those of the former paper, and the similarity between the Bowleaze fauna and that of the early Post-Glacial deposits at Nazeing, Essex, is noted.

1. INTRODUCTION

SINCE THE publication of a detailed account of the Quaternary deposits at Bowleaze Cove near Weymouth, Dorset, by the present writers (Carreck & Davis, 1955), additional evidence has become available, permitting some further inferences to be made concerning one of these deposits, the Early Holocene Loam (*op. cit.*, 78-82).

2. THE EARLY HOLOCENE LOAM

Recent collecting from this horizon, at the original site in the cove, has resulted in the discovery of important additions to the faunal list, as follow.

(a) Mammalia

Clethrionomys sp. One right m_2 . This confirms the tentative recognition of a species of Bank Vole from the deposit, published in 1955 (*op. cit.*, 80).

(b) Mollusca

Acicula fusca (Montagu). Five examples. The species is very rare in the

living state in Dorset; fossil examples were known previously from the Blashenwell tufa (most probably of Atlantic age) and Bronze Age burials at Stockbridge, Hants.

Delete *Columella edentula* (Draparnaud) (*ibid.*, 80) and substitute *Columella columella* (Benz). Six further examples. These more complete specimens show that the earlier identification was in error. *C. columella*, which is perhaps a sub-species of *C. edentula*, is extinct in Britain and has not been recorded previously from the Dorset Quaternary, but is known to occur in the Late Pleistocene or earliest Holocene of Portfield, near Chichester. It is best known from its occurrence in the 'Arctic' Beds of Ponder's End (Middlesex), Nazeing (Essex) and Barnwell Station, Cambridge. At Nazeing it is found to have lived from the Late Pleistocene (Last Glaciation), C^{14} dating > 20,000 years B.P., to the Early Boreal, Zone V, during which it died out (Allison, Godwin & Warren, 1952, 190 and 235). Burchell & Davis (1957, 167) consider, on the basis of molluscan evidence, that at Aylesford, Kent, this form ranges from Late Glacial (Older Dryas Time) to the end of the Boreal. Therefore, although characteristic of sub-arctic climatic environments in Britain during the Last Glaciation, it persisted in this country during progressive amelioration of climate, into the Boreal.

Vertigo substriata (Jeffreys). Two examples. A species previously known in Dorset only from the Blashenwell tufa. At the present it is typical of the more humid north-western parts of the British Isles.

V. genesii Gredler (? = *V. parcedentata* (Braun)). Three examples. There are no previous records of this for Dorset, but it is present in the Pleistocene of West Wittering, Sussex. It occurs in some Pleistocene and Early Holocene deposits but became extinct in Britain, probably by Bronze Age times, although it still lives in Ireland.

Lauria anglica (Férussac). Three examples. *L. anglica* has not been recognised previously in the county, but occurs in the Holocene of Box (Wiltshire), and the Holocene tufa of Totland Bay, Isle of Wight, both probably of Atlantic age. Like *Vertigo substriata*, *L. anglica* is now characteristic of the humid north-western areas of the British Isles.

Clausilia rophi Turton. Two examples. This species has not been recorded previously from any Quaternary deposit in the county, but was found living at Liscombe Bottom, about seven miles NNE. of Dorchester, shortly before 1898, and by the senior author (A. G. D.) in 1956 at Creech Grange, near Creech Barrow, in Purbeck. *C. rophi* is rarely found fossil, and is unknown in the British Pleistocene.

Pisidium subtruncatum Malm. Three examples. In addition, this has been identified recently by Mr. S. P. Dance, as yet without publication, among material collected by the authors from the tufa at Blashenwell.

P. personatum Malm. Four examples. Also determined recently by Mr.

Dance from the authors' material from the Blashenwell tufa, but not previously published.

3. CONCLUSIONS

When these additional molluscan occurrences are considered in relation to those recorded by the authors in 1955 from this deposit, it is seen that the fauna as a whole does not reflect cold conditions but resembles those of the Nazeing series (Allison, Godwin & Warren, 1952, 190-1) as the latter passes up into the deposits of Mesolithic age, in which the sub-arctic fauna becomes modified, no longer stunted, and is accompanied by the arrival of forms indicative of a warmer climate. The forms recorded in the present note suggest damp woodland or damp and shady ground, with some standing water, and therefore support the conclusions reached in 1955 (*op. cit.*, 81). *Columella columella* does not indicate a cold climate in this instance, for it is known to have persisted in a temperate climate into the Boreal phase of Post-Glacial time, and probably to the end of that phase.

A comparison of the entire molluscan fauna of the Early Holocene Loam with those of similar age elsewhere, and the occurrence of *C. columella*, shows that there can be little doubt that the deposit was laid down during part of Mesolithic times. The molluscan evidence also clearly indicates that a temperate climate existed in the region during the time of deposition.

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REFERENCES

- ALLISON, J., GODWIN, H. & S. H. WARREN. 1952. Late-Glacial Deposits at Nazeing in the Lea Valley, North London. *Phil. Trans.*, Ser. B, **236**, 169-240.
BURCHELL, J. P. T. & DAVIS, A. G. 1957. The Molluscan Fauna of some Early Post-Glacial Deposits in North Lincolnshire and Kent. *J. Conch.*, **24**, 164-70.
CARRECK, J. N. & DAVIS, A. G. 1955. The Quaternary Deposits of Bowleaze Cove, near Weymouth, Dorset. *Proc. Geol. Ass., Lond.*, **66**, 74-100.

The Clacton Flint Industry: A Supplementary Note

by S. HAZZLEDINE WARREN

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ABSTRACT: In my Henry Stopes Lecture I recorded an abraded group of artifacts as 'Derivative?'; reasons will now be given for removing the question mark and dividing the Clacton industry into two phases, Primitive and Advanced, the latter having been the subject of the lecture. The present improved definition of the Primitive phase has brought out the superior quality of the retouch in the trimmed flakes of the Advanced phase, which is nearer to the High Lodge industry, the main difference between the two phases being in the trimmed flakes.

The opinion is confirmed that the Clactonian industries are probably rooted in the ancient traditions of the great Pebble Tool cultures.

1. INTRODUCTION

THE MAJORITY of the artifacts of the Clacton channel deposits are seen, by their unabraded condition, to have been made locally. Any trace of weathering is also rare. In my Henry Stopes Lecture (Warren, 1951) I recorded a certain number among them which had suffered great abrasion, but left their interpretation open for future consideration. I have since found a line of evidence that I believe to be significant, in spite of the fact that relative abrasion and patination may often be misleading as a guide to relative date.

2. BLACK-INCLUSION FLINT

In order to make this clear I will first refer to a distinctive variety of banded flint which has long attracted attention among the palaeoliths of Swanscombe and Aylesford. A nearly allied, but not identical, variety of this flint also occurs in NW. Essex. The distinctive structure common to both varieties is particularly well seen in a nodule found some years ago in the Chalky Boulder Clay of Pledgdon (Elsenham Sand Pits) NE. of Bishop's Stortford. This shows that in the first stage the nodules began as

ordinary black (or nearly black) flints with the usual white or grey inclusions and white cortex. At a later stage these became enveloped by variable bands of more translucent and chalcedonic flint of very light brown or other tones. The two stages are clearly revealed by the Pledgdon flint owing to the fact that the original nodule is not completely enveloped by the later bands.

In these flints the dark core (the original nodule) is relatively resistant to ochreous patination, but the surrounding bands readily acquire attractive 'mahogany' tones which emphasise the structure, the whole having a marbled pattern. Both white and black patinations, on the other hand, tend to obscure the structure.

It is not easy to find a short name for this flint that is more than partially correct in meaning. 'Black inclusion banded flint' fairly describes it, while 'marbled mahogany flint' represents its more familiar appearance as modified by ochreous patination.

The Pledgdon flint was used in a local Levallois industry; it differs from the Lower Thames Valley variety in that much of it has a spotted appearance; in fact, Oakley has suggested to me that it probably replaces brecciated chalk.¹ The late J. F. Hayward (1956, 334) traced this flint *in situ* in the top of the Chalk at Stansted, and has also recorded it from the Lea Valley gravels, but I have not succeeded in recognising it among my rather extensive collection of artifacts from the Lea Valley. My own interest has been mainly focused on its use by early man.

In passing down the Thames Valley from London, the first evidence of the use of this flint is in the Crayford Levallois, but it is rather rare. On the north side of the river there is interesting evidence in the sub-Eocene basement bed at Grays, where black-inclusion flint is abundant among the fresh residual flints brought in through the underground solution of the Chalk; but I have not identified it among the green-coated (or true Bullhead) flints.

One would expect the black-inclusion flint to occur in quantity in the Bullhead bed, but at Clacton also where from three to seven per cent of the artifacts are in green-coated flint, I have not yet proved black-inclusion flint which is also green-coated; but I do not doubt that it will be found.

3. THE DERIVED SERIES

I have more than twenty artifacts of the Clacton channels carrying two-age work, that is to say they are abraded, patinated and striated flints re-flaked at a later (post-patination) date. A close study of this two-age group has convinced me that more can safely be defined as derived than I

¹ Dr. K. P. Oakley made the following comment in proof: 'When I made this suggestion I had in mind comparison with the Burnham flint which was a replacement of conglomeratic chalk.' *Proc. Geol. Ass., Lond.*, 55, 170 (1944).

allowed in my Henry Stopes Lecture; but also that an intermediate group should be defined as uncertain.

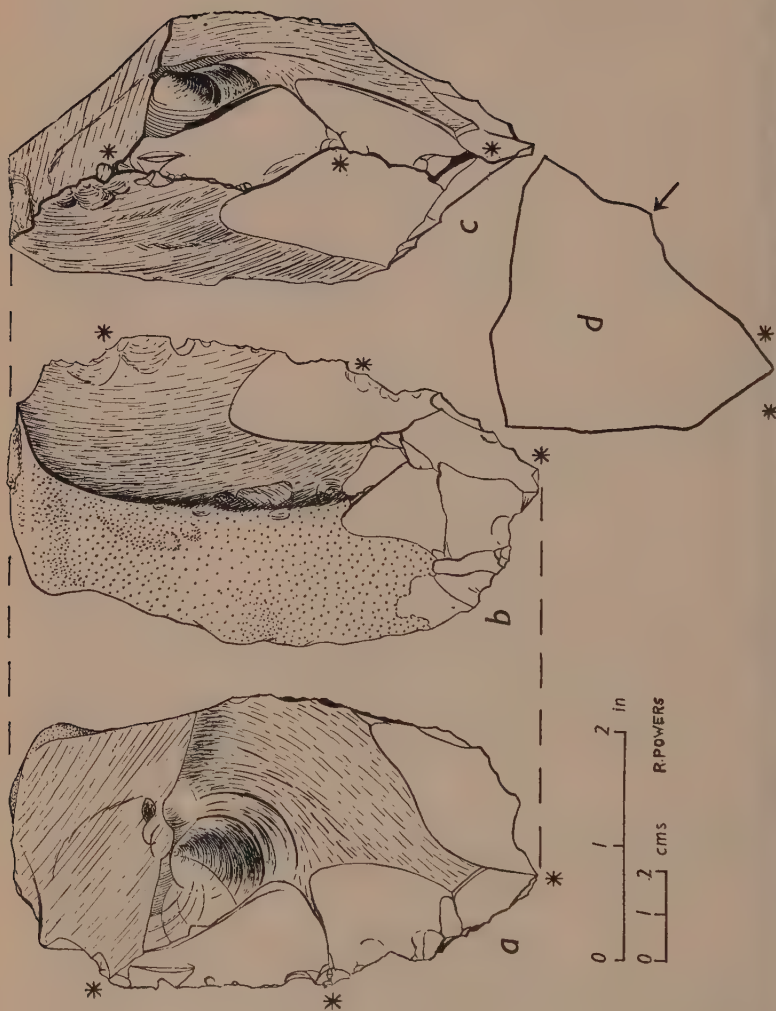
Fig. 1 illustrates the most interesting example of two-age work: this I dug out of the basal gravel in Channel V at Lion Point (Warren, 1955, 1984). In the earlier stage it was a thick, clumsy outside flake made in black-inclusion flint; after ochreous patination, abrasion and striation, it was re-flaked into a flake-chopper during the later stage; in the figure *a* is a view of the inner face of the original flake with a very strong conical bulb, the later flake-facets being drawn (as also in *b* and *c*) in outline only. View *b* is of the outer face, and *c* an edge view showing the low core-angle of about 47° (that is, the true flaking angle seen by the craftsman before striking his blow—the angle from which he chose to work).

The cross-section *d* indicates the balance of the implement in the hand, the arrow pointing to the position of the cone. In each view the stars indicate the zig-zag chopping edge. It is possible that this implement may have been a combined chopper and pointed tool, but to my judgment it is emphatically not a core.

The following are frequencies I have found for the use of black-inclusion flint in various industries. Out of 400 artifacts dug from the basement gravel of Channel V at Lion Point, 281 were contemporaneous, including 23 (8%) of black-inclusion flint, and 53 were abraded, patinated and striated, including 32 (60%) of black-inclusion flint. From the first or Westcliff Channel, 197 artifacts were collected and of these 163 were contemporaneous, including 13 (8%) of black-inclusion flint, and 19 derived with 10 (53%) of black-inclusion flint. Of significant comparisons I have 35% black-inclusion flint in the Swanscombe Clactonian, and 63% in a rather later industry, comparable with that of High Lodge and the Stoke Newington floor', from the Twydall Chalk Pit. (The Twydall collection was obtained from W. H. Cook of Snodland. The pit is situated in the Lower Medway Valley, S. of the Isle of Sheppey. The late Dr. J. F. Hayward recently visited the site and found it much obscured, but had hoped to do further work there.)

In view of these evidences there seems no reason to doubt that while the unabraded series at Clacton were made locally, and are contemporaneous with the deposit, the abraded, patinated and striated group have been drifted from some site nearer to a source of the black-inclusion flint, presumably in the Lower Thames-Medway basin in conformity with the abundance of Lower Greensand chert in the same gravel. The reality of the earlier and later groups is not invalidated because one cannot draw an absolute line between them: one must allow a margin for accidental circumstances on both sides.

Some mistakes in relative dating have been made through taking present-day abrasion on the beach (where much of the collecting has been done) as



being original. Most of the fresh abrasion can be distinguished by comparison with carefully dug material; prolonged beach rolling usually results in a greenish tone of patination.

I have taken striation, although often very slight, as an essential item in defining the derived group, but have not reached a firm opinion on its origin. A few, but not many, of the flints carry numerous short striae in indiscriminate directions, which is a feature typical of the soil-creep hill-drifts. A larger number have longer striae, sometimes in parallel groups crossing the flints in one or two directions only. There is little satisfactory evidence of curved (segmental) striae suggesting the pivoting of ice-floes, such as one sees in the basement bed of the Weybourne Crag. The striae are never so strong as in the Glacial drifts, nevertheless the cumulative evidence is impressive: perhaps the flints were involved in river-valley sludge-streams during a cold period coming between the two phases of the Clactonian.

Fig. 2 illustrates some possible affinities of the bill-hook scraper that is such a well-defined feature of the advanced Clacton industry. My collection



Fig. 2. Suggested affinities of bill-hook form of trimmed flake, Clacton

of the primitive (derived) Clacton does not include anything quite the same, but there are cruder forms such as *A* which are suggestive as possible forerunners of the type. The example, *B*, shows the true bill-hook form of the advanced Clacton phase; others of this type are trimmed to a scraper edge along the line *s-s-s* with the best retouch seen in the Clactonian industry. There are a large number that are much simpler with only one or two deep secondary flakes to make the hollow below the hook, and often

without any trimming along the outer edge; nevertheless the systematic repetition of the type is evidence of some skill. The flakes of the High Lodge (or 'Clacton III') industry frequently carry a trimmed angle as in c (top left) from the Stoke Newington floor; this is probably a modified survival of the 'hook'. The feature of the trimmed angle continues into the true Mousterian.

The later, or advanced, Clacton of the name-site is emphatically nearer to High Lodge than the derived or earlier.

4. THE CORE OR CHOPPER PROBLEM

I would like to refer further to an objection that is raised against accepting the 'choppers' as true bifacial implements: namely, that it is difficult to draw a clear line between these and cores. In reply I would say that the same difficulty is found in later and more highly skilled industries. The working sites include the attempts of beginners, rude forms for rough or casual purposes, trial pieces discarded on account of poor quality material, together with breakages and faults and failures in great variety. I have much of this indefinite waste of Neolithic and Bronze Age date, and there is the same difficulty in drawing the boundary between implements and cores. In fact, the flint worker must sometimes start with one intention, change to another, and finally discard the piece, perhaps giving it an angry smash!

It should not be overlooked that the Clacton choppers are identical with the artifacts accepted as implements in the early Pebble Tool cultures of Africa and Asia; the types usually classed as Abbevillian also occur.

I must add that I now have two or three definite hammer-stones together with others that are doubtful, but these would serve only for the smaller trimming. All are in flint, which is a material that flies to pieces too easily to stand up to prolonged hammering. For that reason, and also because hammer-stones are not easily seen in a deposit with a sticky matrix, I still prefer to leave the problem of hammer-stone or anvil-stone open. Perhaps flaking was done by both methods. Certainly I find the hammer-stone method the easier and more satisfactory for doing Clactonoid flaking.

The chopper with two-age working has been deposited in the British Museum (Natural History) where I have already placed all the artifacts used to illustrate the Henry Stopes Lecture.

ACKNOWLEDGMENTS

Finally, there only remains the pleasing duty of expressing my warm thanks for the help I have received in preparing the foregoing notes from both Dr. Kenneth Oakley and the late Dr. J. F. Hayward.

APPENDIX

Since the above was written I have seen Mr. J. Wymer's account (1957) of his new Clactonian site at Grays. It is clear that this is not the advanced Clacton of the name-site; in the future, it may be possible to subdivide the more primitive Clactonian, but at present I think the attempt would be premature.

REFERENCES

- HAYWARD, J. F. 1956. Geological Records from the Valley of the River Stort. *Essex Nat.*, **29**, 333.
- WARREN, S. H. 1951. The Clactonian Flint Industry: A New Interpretation. *Proc. Geol. Ass., Lond.*, **62**, 107.
- . 1955. The Clacton (Essex) Channel deposits. *Quart. J. geol. Soc. Lond.*, **111**, 283.
- WYMER, J. 1957. A Clactonian Flint Industry at Little Thurrock, Grays, Essex. *Proc. Geol. Ass., Lond.*, **68**, 159.

Easter Field Meeting: The Lower and Middle Jurassic Rocks of the Bristol District

18-22 April 1957

Directors: D. T. DONOVAN and T. R. FRY

Report by D. T. DONOVAN

Received 4 January 1958

THE ASSOCIATION has previously held excursions in the area in August 1880 (Sollas, 1881), at Whitsun 1901 (Winwood, 1901; Reynolds, 1901; Buckman, 1901; Morgan & Winwood, 1901), at Easter 1919 (Reynolds & Tutchter, 1919), at Easter 1929 (Reynolds *et al.*, 1929), and at Easter 1947, under the leadership of the late Dr. Stanley Smith (no report published). These excursions were all of general scope, but the present one consisted of a more specialised study of certain Jurassic rocks. About twenty members and friends attended and assembled in the Geology Department of the University on Thursday evening for an introductory talk.

I am much indebted to Dr. D. V. Ager, who has made almost all the brachiopod determinations quoted in this report, and to Mr. R. V. Melville, who is responsible for the majority of the gastropod and lamelli-branch names. Sgt. P. Cambridge has also supplied me with a list of material collected by him, which has been incorporated in the report.

Friday, 19 April

The party left Bristol by the Wells road, and after the coach had successfully negotiated a very narrow lane the pit in Lower Lias Clays at North Wick (584656)¹ was visited. The pit was opened about 1950 and has not been previously described. Mr. Fry gave an account of the section which he has measured:

5. Clay with ochreous nodules. <i>Androgynoceras</i> sp. ind. probably	ft.	in.
from these beds seen	30	0
4. Impersistent, marly limestone; <i>Lytoceras fimbriatum</i> (J. Sow.) to		8
3. Clay with belemnites	10	0

¹ All Grid References are found within the 100 km. square 31.

2. Impersistent bed of hard, grey limestone nodules, of irregular, lenticular shape. <i>Tragophylloceras ibex</i> (Quen.), <i>Acanthopleuroceras maugenestii</i> (d'Orb.), <i>A. valdani</i> (d'Orb.), <i>Liparoceras cheltiense</i> (Murch.), <i>Piarorhynchia</i> cf. <i>triplicata</i> (Quen.), <i>Zeilleria</i> cf. <i>vicinalis</i> (Schlotheim), <i>Parainoceramus ventricosus</i> (J. de C. Sow.), <i>P. substriatus</i> (Münster in Goldfüss)	ft.	in.
1. Clay seen	1	0

belemnites of the genera *Hastites*, *Pseudohastites* and *Passaloteuthis* (as used by Lang, 1928) were found, presumably washed out of Bed 3. The following fossils, whose exact horizon is not known, have also been recovered: *Pleurotomaria* aff. *amalthæi* Quenstedt, *Plicatula spinosa* J. Sow., *Thlamys prisca* (Schlot.), *Meleagrinella* sp. and *Pseudopecten acuticosta* Lamarck).

Bed 2 belongs to the Ibex Zone, Valdani Subzone. Specimens of *Androgynoceras* found loose suggest the presence of the Davoei Zone, but in opinion as to whether the intervening Centaurus Subzone is present cannot be given.

The summit of Dundry Hill was then gained, and the party visited the Southern Main Road Quarry (567654), to examine Lower, Middle and Upper Inferior Oolite (Buckman & Wilson, 1896, 691). The quarry has been disused for about thirty years and had become obscured, but a section has been re-excavated by members of the Geological Section of the Bristol Naturalists' Society. The road-bank north-west of Dundry Church was then visited (555671), but the section was found to be indifferent. When cut back about twenty years ago this bank showed about thirty feet of clays with *Dumortieria*, succeeded by the whitish, marly Aalensis Bed, a few inches thick, and this by the basal limestones of the Lower Inferior Oolite. On the walk back to the coach across the field above the road, the disturbed ground due to ancient workings in the Dundry Freestone was noted. After lunch the Church Quarry (556666) was examined. It still shows a good section of about twelve feet of the freestone, overlain by about six feet of the Coralline Beds.

The first mention of quarries at Dundry is in a document of 1292-3 (Gough, 1930, 52). According to information from Mr. Frank S. Clements, large-scale working of Dundry Freestone ceased about 1914. The Church Quarry continued in work until 1921, when a new quarry was opened by Mr. Clements' father about 300 yards south-south-west of the church, as a result of the proving of the freestone in a well. The stone was found to be of inferior quality and working was soon discontinued.

The section in the new quarry, continued downwards by the well-sinking, was recorded by Mr. Fry, and has not previously been published. The section is:

		ft. in.
UPPER INFERIOR OOLITE	Coral Bed: Coarsely granular limestone with lenticles of yellowish clay; crystalline and rubbly in places, with coral and shell fragments. Bedding, where visible, is very irregular. <i>Rugitela waltoni</i> (Dav.) and <i>Isastraea richardsoni</i> Edwards & Haime are common towards the base seen	18
	Dundry Freestone: Light grey, granular, slightly crystalline limestone; massive, in three or four beds	11
	Upper Trigonía Grit: Granular, slightly ironshot, grey limestone with pebbles of limonite near the base. <i>Astarte manseli</i> S. S. Buckman, <i>Trigonía costata</i> J. Sow., <i>Montlivaltia delabechii</i> E. & H.	1
	(Non-sequence: the 'Brown Ironshot' is absent, as is usual in the western part of the hill.)	
LOWER & MIDDLE INFERIOR OOLITE	Thicknesses of component parts not accurately determined; appears to have been essentially similar to section at Castle Farm (Buckman & Wilson, 1896, 676) total	16
UPPER LIAS	Aalensis Bed: Pale blue, soft, argillaceous limestone, in two beds with clay parting. The top planed and oyster-covered. <i>Pleydellia aalensis</i> (Zieten), <i>Pleurolytoceras hircinum</i> (Schlot. in Quen.), <i>Alocolytoceras leckenbyi</i> (Lyc.)	2
	Dumortieria Beds: Bluish, sandy clay, with three beds of soft, bluish limestone. <i>Dumortieria</i> cf. <i>multicostata</i> S. S. Buckman about 5 ft. 0 in.	45
	Bluish sandy clay, with a little nodular limestone; belemnites. In the absence of fossil evidence this bed is included in the Dumortieria Beds, in accordance with the practice of Buckman & Wilson (1896, 677) 40 ft. 0 in.	
	Striatulum Beds: Very dense limestone, brown to yellow, with granules and ooliths of limonite in places. <i>Grammoceras thouarsense</i> (d'Orb.) on the surface of the bed, <i>Pseudogrammoceras expeditum</i> S. S. Buckman; belemnites abundant	2
	Bifrons Bed: Bluish limestone speckled with iron oxide, containing numerous irregular pebbles of limonite and a few of bluish-grey sandstone. Fossils heavily coated with iron oxide. <i>Hildoceras bifrons</i> (Brug.), <i>H. semicosta</i> S. S. Buckman, <i>Harpoceras mulgravium</i> (Young & Bird), <i>H. cf. falcifer</i> (J. Sow.), <i>Serpula</i> in masses	1
MIDDLE LIAS	Margaritatus Bed: Dark brown limestone, with scattered limonite ooliths, and a few irregular pebbles of calcareous sandstone. <i>Pleuroceras salebrosum</i> Hyatt, <i>Lima (Antiquilima)</i> aff. <i>succincta</i> (Schlot.), <i>Zeilleria cornuta</i> (J. de C. Sow.), ' <i>Rhynchonella</i> ' <i>acuta</i> J. Sow. about	1
LOWER LIAS?	Bluish and brown clays, age uncertain; in similar clays at Hill Farm near Maes Knoll, <i>Androgynoceras</i> was found between 30 and 60 feet below the base of the Margaritatus Bed, in 1930 seen	10

Dundry was now left behind for Broadfield Down, an anticline in the Carboniferous Limestone which influenced sedimentation in Hettangian times. At Lulsgate Quarry (516657), worked for Carboniferous Limestone, the party first examined the conglomeratic basal beds of the Lias, discovered by Mr. Fry. About nine feet of beds are seen, resting on a fairly even surface of Carboniferous Limestone, and consisting of pebbles of that rock in a calcareous matrix. Fossils are poorly preserved but *Placunopsis* sp. and *Pteria* cf. *alfredi* (Terquem) were recovered and identified by Mr. R. V. Melville. They do not help to determine the exact age of the conglomerates, but this is either Hettangian or early Sinemurian, for an upper limit is provided by the occurrence described in the next paragraph.

The surprise of the day was provided when members descended to the floor of the quarry to inspect the filling of a fissure in the Carboniferous Limestone. As well as reddish material, possibly Triassic, the fissure contained yellow, silty rock, and blue clay of Jurassic aspect. It also held numerous calcareous septarian nodules, up to one foot or more across, some of which yielded well-preserved ammonites and other fossils. The following species have been identified: *Caenisites plotti* (Reynès), *Arnio-ceras* sp. (group of *bodleyi* (J. Buckman)), *Gryphaea* sp., *Pseudolimea pectinoides* (J. Sow.) and fragments of other lamellibranchs, gastropods and brachiopods. The ammonites indicate the Turneri Zone of the Lower Lias, and the nodules were presumably derived from clays such as are believed to occur at Barrow Gurney reservoirs, about two miles to the north-east, where *Ammonites turneri* is recorded (Woodward, 1893, 136). No such beds are present in the overburden at Lulsgate Quarry, and the nodules are presumed to have been let down into the fissure from an overlying clay deposit, before the latter was removed by denudation.

The road was then taken to Downside, west of Lulsgate Bottom, and a long-disused quarry, south of the road (493662), in massive, porous detrital limestones of Hettangian date was visited. This may be the quarry recorded by Woodward (1893, 133, 293) who noticed some resemblance in lithology to the Doultong Stone, and also to the Hettangian Sutton Stone in Glamorganshire. About fifteen feet of beds are still visible. Despite its coarse texture and cavernous nature, this stone was quarried as a freestone, and was known as Brockley Down Stone. The following lamellibranch species were obtained: *Ceratomya* sp. nov.? cf. *C. petricosa* (Simpson), *Gervillella* cf. *hagenowi* (Dunker), *Liostrea* sp., *Modiolus laevis* (J. Sow.), and *Parallelodon hettangiensis* (Terquem).

Continuing through Brockley Combe, a dry valley in the Carboniferous Limestone, the main Bristol-Weston-super-Mare road was reached and followed through Weston to Uphill, where the road-cutting described by Kellaway & Oakley (1934) was noted in passing. The Keuper is still well exposed, but the Rhaetic part of the section has become obscured. Lastly,

the section in Upper Pleistocene and later deposits, on the southern side of Brean Down, was examined. The section is being studied by Mr. A. M. ApSimon and the writer, and a detailed report is in course of preparation.

Saturday, 20 April

The day was devoted to facies of the Lias and Inferior Oolite in the East Mendip region. The first stop was at Wurt Pit (559539) above East Harptree, which is the 'large pit' described by Woodward (1876, 106; 1893, 124). The pit is presumed to have originated by collapse of a solution cavity in the underlying Carboniferous Limestone; an example of such a cavity is Lamb Lair Cavern, about a mile to the north-west. The depth was underestimated by Woodward, unless it has increased since his visit; it is now forty feet or more. Near the top of the pit is a nearly continuous exposure of about ten feet of massive chert. The lower part of the pit may penetrate the Rhaetic sands reported to exist in the area (Woodward, *op. cit.*, 125), but nothing is visible *in situ*. Fossils collected from loose blocks of the chert by the party, and during previous visits, include:

Cephalopoda: *Psiloceras* sp. (group of *plicatum* Quen.).

Lamellibranchia: *Astarte gueuxi*? d'Orbigny, *Cardinia* sp. cf. *exigua* Terquem, *Lima* (*Plagiostoma*) *dunravenensis* Tawney, *Liostrongya hisingeri* (Nilsson), *Mactromya arenacea* (Terquem), *Modiolus* cf. *langportensis* Richardson & Tutchter, *Myoconcha psilonoti* Quenstedt, *Pholadomya fraasi* Oppel, *Pinna semistriata* Terquem, *Pleuromya tatei* var. *altior* Richardson & Tutchter, *Protocardia phillipiana* (Dunker), *Pseudolimea hettangiensis* (Terquem), *Terquemia multicostata* (Münster).

Gastropoda: *Ataphrus* sp., *Pleurotomaria* cf. *wanderbacki* Terquem, *Procerithium trigemmatum* (Wilson), *Pseudomelania* sp., *Ptychomphalus rotellaeformis* (Dunker), *Zygopleura* sp.

Anthozoa: *Coelostylinia thieryi* Terquem.

Reynolds (1921, 132), presumably following Woodward (1876, fig. 11, 107), said that the cherty beds represented the White Lias and the Planorbis and Johnstoni Beds of the Blue Lias. The forms now recorded are principally ones which are familiar from the basal beds of the Blue Lias in the district.

The road was then taken, past the Castle of Comfort and the Hunters Lodge Inn, to the south flank of the Mendips, to visit the section through Keuper Tea-Green Marls, White Lias and Blue Lias described by Brodie (1866) at Milton Lane (549473) and previously visited by the Association in 1909 (Richardson, 1910, 225). A passable section is still exposed, except that the Westbury Beds are obscured. The section is of interest in showing almost 'normal' facies of the White and Blue Lias, in close proximity to the Mendips. Since Brodie's description a detailed diagrammatic section, by H. B. Woodward, has been published by the Geological Survey (Vertical Sections, Sheet 46, No. 14). Woodward notes beds with fish-scales in the

Tea-Green Marls but the fish-scales were not rediscovered. Several *Caloceras* were found in loose blocks of Blue Lias.

Shepton Mallet was next visited, to examine the Downside Stone facies of the Hettangian. In the disused quarry behind Messrs. Hobbs Bros. works (622446) on the west side of the Bristol road below Downside, the basal unconformity was examined. The beds were seen to rest on Carboniferous Limestone dipping steeply to the south. The surface of the Carboniferous Limestone is irregular, with a relief of a foot or more, the irregularities being apparently related to harder and softer strata. The Downside Stone is a pale cream-coloured, coarse-grained cavernous weathering limestone, with abundant lamellibranchs, gastropods and belemnites. Near the base it carries masses of bluish chert. *Ctenostreon tuberculatus* (Terquem), *Lima (Plagiostoma) valoniensis* (Defrance) and *Liostrea cf. laevis* (Tawney) were collected. The old Viaduct Quarry (Woodward, 1893, 88) still shows a good section of about thirty feet of Downside Stone, but was passed by in favour of a fresh section at the quarry in work near Beacon Farm (635448), not previously recorded in detail (noted by Loupekiné, 1956, 160, but wrongly said to be Doulling Stone). The following section was seen:

Buff, crystalline limestone, the lower part coarse-grained, with shells, the upper becoming finer with fewer fossils ... seen	ft.	in.
	8	6
Conglomerate, with pebbles of Carboniferous Limestone and of chert, passing up into the bed above		2
Comparatively fine-grained limestone	1	6
Porcellaneous limestone of White Lias lithology, with veins and specks of calcite		5
Similar to the bed above, but coarser-grained and less pure ...		7
Granular, crystalline limestone, in finer and coarser-grained beds, similar to the top beds of the section; gastropods and lamellibranchs, mainly preserved as moulds seen	11	6

The conglomerate is present in identical form at the Viaduct Quarry, a mile distant. If the White Lias-like bed really does represent that formation, then the lower part of the section must belong to the Rhaetian stage. A fortunate find of a specimen of *Caloceras* in a loose block showed that part, at least, of the section falls into the Planorbis Zone of the Hettangian stage.

The next stop was at the well-known quarry at Doulling in the Doulling Stone of the Upper Inferior Oolite (647435) (Richardson, 1907, 395). The quarry is still in work and shows an excellent section. There was some discussion of the general belief, apparently first suggested by Woodward (1894, 89), and repeated without comment by Richardson (*op. cit.*, 388), that the stone is largely made up of crinoid ossicles derived from the Carboniferous Limestone. It was agreed that this was not inconsistent with the fragments visible in the stone, although it would be difficult to prove.

From Doultling the Mendip axis was crossed at Beacon Hill and the road taken to Upper Vobster, where members examined the large quarry in much-disturbed Carboniferous Limestone, and the thin Lower Lias resting on the surface of the latter at the eastern end (707497). The Lias was first noticed by Richardson (1909, 222), and briefly described by Tutchter & Trueman (1925, 613). The quarry was also visited by the Association in 1940 (Cox, 1941, 29). On the present occasion it was seen that the planed surface of Carboniferous Limestone, noticed by all previous observers, contains irregular pockets, several feet deep, with smooth walls apparently of solutional origin. These pockets contain greyish-green and chocolate coloured clay, in which are numerous small black bodies, many too worn to be recognisable, but others identified as fish-scales. Another pocket, much obscured by vegetation, showed bright red and grey-green clay, presumed to be Triassic in origin.

The principal attraction lay in collecting from the Lias. Most of the fossils have been obtained from a fossiliferous layer at the base, only an inch or two thick, the limestones above being comparatively barren. Some, but not all, of the fossils in the fossil bed are phosphatised. In some fossils the phosphatisation is partial only, and in his notes on the brachiopods, Dr. Ager commented: 'Although the preservation of the fossils suggests that some have been derived, it is not possible to distinguish more than one zonal assemblage.' A fossil list was published by Richardson; a revised one, based principally on recent finds, follows:

Cephalopoda: *Paltechioceras* aff. *bavaricum* (Böse), *P. oosteri* (Dumortier), *P. flexicostatum* (Trueman & Williams),¹ *P. rectecostatum* (Trueman & Williams),² *Echioceras simile* (Trueman & Williams), *Oxynoticeras* (*Gleviceras*) *subguibalianum* (Pia), *O. (G.) victoris* (Dumortier), *Eoderoceras* sp., *Apoderoceras* sp., *Liparoceras* (*Vicinodoceras*) sp., ? sp. nov. (Bristol Univ. Geol. Dept. No. 2859, Fry coll.), *Nautilus* sp.

Brachiopoda: *Cincta numismalis* (Lamarck) variants named *C. nummus* & *C. dives* by Buckman, 1907, *Cirpa* sp. nov. (= *Rhynchonella variabilis* auctt., non Schlotheim), *Furcirhynchia furcata* Buckman, *Gibbirhynchia curviceps* (Quenstedt), *Lobothyris ovulum* (Quenstedt), *Quadratrhyrchia* (?) sp. ind., *Rimrhynchia anglica* (Rolloer) (= *R. rimosiformis* Buckman), *Spiriferina rostrata* (Schlotheim) cf. var. *lata* Wolleemann, *S. walcotti* (J. de C. Sowerby), *S. sp. cf. S. pinguis* (Zieten), *Zeilleria* cf. *Z. ellioti* Ager, *Z. indentata* (J. de C. Sowerby), *Z. sarthacensis* (d'Orbigny), *Z. subnumismalis* (Davidson).

Gastropoda: *Pleurotomaria* cf. *mosellana* Terquem, *P. sp.* (group of *P. principalis* Chapuis & Dewalque).

Lamellibranchia: *Chlamys* cf. *subulata* (Münster), *Gryphaea cymbium* Lamarck, *Lima* (*Plagiosoma*) sp., *Mactromya cardioides* (Phillips), *Modiolus* sp., *Pholadomya corrugata* Koch & Dunker, *Pleuromya costata* (Young & Bird), *Plicatula* sp., *Pseudolimea* aff. *pectinoides* (J. Sowerby).

Anthozoa: *Oppelismilia mucronata* (Duncan).

¹ The holotype is from Vobster, figured by Trueman & Williams (1925, pl. 3, figs. 2a, b). This is the type species of *Vobstericeras* Trueman & Williams, regarded as synonymous with *Paltechioceras* (see Donovan, 1958, 17).

² Noted from Vobster by Trueman & Williams (1925, 724).

The earliest horizon represented by the fauna listed is the *Raricostatum* Subzone of the *Raricostatum* Zone, indicated by *Echioceras*; the *Aplanatum* Subzone is also indicated by the various species of *Paltechioceras*, which are the most common ammonites at Vobster. *Apoderoceras* belongs to the lowest part of the succeeding Jamesoni Zone, and this horizon is also suggested by several of the brachiopods, namely *Cincta numismalis*, *Rimirhynchia anglica* and *Spiriferina rostrata* cf. var. *lata*.

The most interesting member of the ammonite fauna is the *Vicininodicer*, a subgenus of *Liparoceras* characterised by paired tubercles, and ancestral to *Liparoceras* s.s. It does not agree with the only named species, *L. (V.) simplicicosta* (Trueman). The evidence, admittedly negative, of the absence from Vobster of later Jamesoni Zone ammonites, such as *Uptonia* and *Polymorphites*, indicates that *Vicininodicer* may have existed already early in the Jamesoni Zone.

With regard to the brachiopods, Dr. Ager comments: 'The variety of the fauna is interesting, and is only comparable in the British Lias to that of the Spinatum Zone in the south-western counties. There are in fact many points of resemblance between the Vobster fauna and that of my Bridport and Ilminster sub-provinces (Ager, 1956). All the genera except *Cincta* and *Rimirhynchia* are common to both, and these two exceptions are closely related to *Zeilleria* and *Furcirhynchia* respectively, of the same faunas. At least one species (*Zeilleria subnumismalis*) is identical and most of the others are obviously close relations. In both these faunas there is a preponderance of forms of southern aspect such as *Cirpa*, *Furcirhynchia* and species of *Zeilleria*.'

In addition to the fauna listed above, a single example of *Promicroceras* was found in a phosphatic nodule perforated by borings. It indicates derivation of material from a deposit of the Obtusum Zone, and recalls the evidence from certain brachiopods collected in 1940 (Cox, *loc. cit.*) which suggest the presence of elements derived from the Semicostatum Zone. These occasional finds demonstrate the former existence of earlier Lias deposits, now destroyed.

A roadside halt was made at Badgers Cross (629484) to examine loose blocks of a local facies of the Inferior Oolite. The rock, a dense, decalcified sandstone, has not been seen *in situ* but blocks up to several feet across are abundant on the plateau at about 720 feet O.D. south-east of Gurney Slade, and are taken to be the last remnants of an outlier now destroyed by denudation. In the last century the Geological Survey (One-Inch Old Series, Sheet 19) took this rock to be Liassic in age, presumably by analogy with the beds at Wurt Pit (p. 134) which are somewhat similar in lithology. Some blocks carry abundant moulds of fossils and collecting by Miss P. L. Robinson has now shown that the rock is in fact of Inferior Oolite age (Robinson, 1957, 274, 281). The occurrence is of interest as showing that,

west of its main outcrop (in normal facies), the Inferior Oolite passed into a siliceous facies, analogous with that developed in the lower part of the Lower Lias above Harptree.

The last halt on this day was at Gurney Slade, to see the Liassic 'dyke' described by Charles Moore (1867, 491) and recently studied by Miss P. L. Robinson (1957, 267-9, 280) (623500). The fissure-filling, left standing by quarrying of the Carboniferous Limestone, displays vertical stratification, and includes material of Triassic and early Liassic date.

Sunday, 21 April

The Wells road was taken from Bristol and at Clutton the right-hand turning followed to Sutton Hill Quarry (Stowey Quarry in Loupekin, 1956, 160). The quarry is not at present worked so deep as it was when the section was recorded by the writer (Donovan, 1956, 192), and the White Lias is not exposed. The Blue Lias beds of the Planorbis Zone are still well seen, and many fossils were collected. An interesting find by Mr. F. S. Ross was a possible *Semuridia*, which if correctly placed in this genus is the earliest known example. The usual basal Lias fossils were found, and also *Pinna* cf. *semistriata* Terquem.

The next stop was at Corston Field Quarry (Donovan, 1956, 196), which also was rather disappointing. The quarry is now very shallow, a maximum of about six feet of the limestones and shales of the Angulata Zone being seen, and fossils not abundant apart from *Gryphaea*. The base of the Bucklandi Zone (Conybeari Subzone) is no longer exposed in the working face, but may be seen in an old face under the far side of the hedge which limits the western side of the quarry.

After lunch at the Globe, Newton St. Loe, Bath was skirted and the coach ascended the plateau south of the city, capped by Great Oolite Limestones. These were examined at Upper Lawn Quarry, Shaft Road, Combe Down (766624), which shows about thirty-three feet of massive, pale brown oolite with abundant comminuted shells. All but the top nine feet is worked as freestone. This is one of the only two quarries on the plateau still in work. The Midford Road was then joined and followed to the top of Midford Hill, where a pair of disused quarries at a sharp bend in the road, about seven-eighths of a mile north of Hinton Charterhouse (769595), together give a section through the greater part of the Great Oolite Limestones.

A necessarily devious route was then followed, via Hinton Charterhouse and Limpley Stoke, to Murhill, near Winsley, a Great Oolite locality well known in the last century. The section was first described by Lonsdale (1832, 253), and later by Wickes (Winwood & Wickes, 1893, 134) on the occasion of the last visit by the Association. Since that occasion, Winsley Chest Hospital has been built on the site, and the Secretary, Mr. T. A. W.

Carlisle, kindly allowed the party to examine the section (795608). The quarry shows about seventy feet of oolites, ragstones and limestones of the Great Oolite Series.

Monday, 22 April

The day was devoted to an examination of the facies in the Great Oolite Series in the South Cotswolds, comprising the central part of the area described by Arkell & Donovan (1952). Since the itinerary for this excursion is to be published in the Association's Centenary Guides, a detailed account of the day need not be given here. A fauna collected from the Cross Hands Rock at Binley Farm, and not previously recorded, may be noted. In addition to the brachiopods already recorded (Arkell & Donovan, 1952, 239) Mr. Melville and others obtained:

Gastropoda: *Nerinella striata* (J. Buckman).

Lamellibranchia: *Anisocardia truncata* (Morris), *A. (Antiquicyprina) davidsoni* (Lycett), *Eopecten* sp., *Lima (Plagiostoma) minchinhamptonensis* Cox & Arkell, *Lithophaga fabella* (J. A. Eudes-Deslongchamps), *Lucina bellona* d'Orbigny, *Pholadomya lirata* (J. Sowerby), *Trigonia* sp.

At Starveall quarries (Arkell & Donovan, 1952, 236) *Liostrea hebridica* Forbes var. *elongata* Dutertre was collected, *Placunopsis socialis* Morris & Lycett was noticed in abundance, and *Pseudolimea duplicata* (J. de C. Sowerby), and fragments of *Holactypus*? and of a Nucleolitid sea-urchin were obtained. The quarry in the Boxwell Rock at Boxwell (Arkell & Donovan, 1952, 237) yielded *Chlamys (Radulopecten) hemicostata* (Morris & Lycett) and *Pseudolimea* aff. *scabrella* (Terquem & Jourdy), a variant with more numerous ribs than the holotype. The last species does not seem to have been previously recorded from Britain.

LIST OF REFERENCES

- AGER, D. V. 1956. The Geographical Distribution of Brachiopods in the British Middle Lias. *Quart. J. geol. Soc. Lond.*, **112**, 157-88.
- ARKELL, W. J. & D. T. DONOVAN. 1952. The Fuller's Earth of the Cotswolds, and its Relation to the Great Oolite. *Ibid.*, **107**, 227-53.
- BRODIE, P. B. 1866. Notes on a Section of Lower Lias and Rhaetic Beds, near Wells, Somerset. *Ibid.*, **22**, 93-5.
- BUCKMAN, S. S. & E. WILSON. 1896. Dundry Hill; its upper portion, or the Beds marked as Inferior Oolite (g 5) in the maps of the Geological Survey. *Ibid.*, **52**, 669-720.
- BUCKMAN, S. S. 1901. Excursion to Dundry Hill. *Proc. Geol. Ass., Lond.*, **17**, 152-8.
- COX, L. R. 1941. Easter Field Meeting, 1940. Bath. *Ibid.*, **52**, 16-35.
- DONOVAN, D. T. 1956. The Zonal Stratigraphy of the Blue Lias around Keynsham, Somerset. *Ibid.*, **66**, 182-212.
- . 1958. The Lower Liassic Ammonite Fauna from the Fossil Bed at Langeneckgrat, near Thun (Median Prealps). *Mém. Soc. pal. Suisse, Basel*, no. **74** (2).
- GOUGH, J. W. 1930. *The Mines of Mendip*. Oxford.

- KELLAWAY, G. A. & K. P. OAKLEY. 1934. Notes on the Keuper and Rhaetic exposed in a road-cutting at Uphill, Somerset. *Proc. Bristol Nat. Soc.*, (4) 7 (6), 470-88.
- LANG, W. D. 1928. The Belemnite Marls of Charmouth, a Series in the Lias of the Dorset Coast. *Quart. J. geol. Soc. Lond.*, **84**, 179-222.
- LONSDALE, W. 1832. On the Oolitic District of Bath. *Trans. geol. Soc. Lond.*, (2) 33 241-76.
- LOUPEKINE, I. S. 1956. Mining and Quarrying in the Bristol District, 1955. *Proc. Bristol Nat. Soc.*, **29**, 155-61.
- MOORE, C. 1867. On Abnormal Conditions of Secondary Deposits when connected with the Somersetshire and South Wales Coal-Basins, and on the age of the Sutton and Southerndown Series. *Quart. J. geol. Soc. Lond.*, **23**, 449-568.
- MORGAN, C. L. & H. H. WINWOOD. 1901. Excursion to Avon Gorge and Aust Cliff. *Proc. Geol. Ass., Lond.*, **17**, 159-66.
- REYNOLDS, S. H. 1901. Excursion to Tortworth. *Proc. Geol. Ass., Lond.*, **17**, 150-2.
- & J. W. TUTCHER. 1919. Excursion to the Bristol District. *Ibid.*, **30**, 114-21.
- . 1921. *A Geological Excursion Handbook for the Bristol district*. 2nd ed. Bristol.
- & others. 1929. Excursion to Bristol District. *Proc. Geol. Ass., Lond.*, **40**, 171-6.
- RICHARDSON, L. 1907. The Inferior Oolite and Contiguous Deposits of the Bath-Douling District. *Quart. J. geol. Soc. Lond.*, **63**, 383-422.
- . 1909. Excursion to the Frome District, Somerset. *Proc. Geol. Ass., Lond.*, **21**, 209-28.
- ROBINSON, P. L. 1957. The Mesozoic Fissures of the Bristol Channel area and their Vertebrate Faunas. *J. Linn. Soc.*, **43**, 260-82.
- SOLLAS, W. J. 1881. Excursion to Bristol. *Proc. Geol. Ass., Lond.*, **6**, 396-402.
- TRUEMAN, A. E. & D. M. WILLIAMS. 1925. Studies in the Ammonites of the Family Echioceratidae. *Trans. roy. Soc. Edinb.*, **53**, 699-739.
- TUTCHER, J. W. & A. E. TRUEMAN. 1925. The Liassic Rocks of the Radstock District (Somerset). *Quart. J. geol. Soc. Lond.*, **81**, 595-666.
- WINWOOD, H. H. & W. H. WICKES. 1893. Bradford-on-Avon. *Proc. Geol. Ass., Lond.*, **13**, 132-7.
- . 1901. Report of Excursion to Aust Cliff. *Ibid.*, **17**, 163-6.
- WOODWARD, H. B. 1876. Geology of East Somerset and the Bristol Coal-fields. *Mem. geol. Surv. U.K.*
- . 1893. The Jurassic Rocks of Britain. 3. The Lias of England and Wales (Yorkshire excepted). *Mem. geol. Surv. U.K.*
- . 1894. *Ibid.* 4. The Lower Oolitic Rocks of England (Yorkshire excepted). *Mem. geol. Surv. U.K.*

Space, Time and Species

by C. W. WRIGHT, M.A., F.G.S.

Presidential Address delivered 1 March 1957

THE RELATIONSHIP of space, time and species constitutes the central problem of geological correlation. Despite all the recent advances in methods of estimating or calculating the ages of igneous rocks, the results are only valuable to the extent that the rocks in question can be placed in the geological column. The partition of that column and correlation from one area to another depend on knowledge of the occurrence of particular species of fossils. We must therefore consider from time to time what we mean by species and how species extend in, and also vary with, space and time. I do not propose to discuss in detail definitions of the term species—often a fruitless business. Rather by discussing certain aspects of extension in space and time I hope to throw some light on the concept of species and on the use of species by geologists.

During the last few decades we have seen great advances in the understanding of certain facts and factors that are of great importance to geologists as well as to biologists. There have been marked advances in the appreciation of the genetic and environmental basis of the creation of subspecies and species. The most obvious benefits of this work have been in connection with geographical subspecies and clines and in the establishment of the pre-eminent importance of isolating mechanisms in securing and fixing the potential changes that are made possible by gene mutation. Among the specific problems of interest to geologists that have received much attention lately one may quote those of sympatric and 'ring' species. The former problem is that of deciding on the method of formation of pairs of closely allied but distinct species occupying the same or overlapping geographical areas. 'Ring' species are those that show a cline in which one or more characters vary continuously and in which the two ends of the cline come to overlap; thus the carrion and hooded crows and herring and lesser black-backed gulls are two pairs of birds whose members are perfectly distinct in this country, but in the case of each pair the so-called species grade imperceptibly into each other if followed round their ring-shaped area of distribution. It is significant, though entirely natural, that a large part of recent work of this type is concerned with land animals and plants and that there is relatively little such work done on marine invertebrates. The latter of course form most of the subject matter of palaeontology. Despite all the deep-sea expeditions and the long continued and remarkable work of marine biological stations, the biology and ecology of

the organisms in the sea, particularly the invertebrates, are far less well understood than the biology and ecology of terrestrial animals and plants.

This fact must carry a warning to us. The principle of uniformity is indeed the basis of much of geology, but palaeontologists and neontologists alike must be careful not to read into the study of marine fossils principles and hypotheses drawn uncritically from the study of terrestrial organisms. With this warning let us consider some of the aspects of the extension of fossil species in space.

Palaeontologists, faced with the puzzles of distribution and long-range correlation, have long been alert to the possibility of discovering examples of fossil geographical subspecies and clines. Intrinsically, however, the probability of proving examples of these phenomena is small. It is rare in geology, if indeed it ever is the case, that one can be so certain of the absolute contemporaneity of two rocks in different localities that it is possible to rule out time as a factor in such differences as there may be between the fossils. One of the commoner types of cline recorded today is the size cline, genetically controlled variation in adult size with temperature, latitude or some other factor. Yet it would be hard to be sure that a thin bed of limestone, for example, in which a species of fossil was progressively larger from south to north was not in fact diachronous. Indeed what is presumably genetically controlled variation in size with time is common. A good example is that of certain genera of chalk starfishes or the well-known case of the sea-urchin *Micraster*.

On the other hand the palaeontologist appreciates that any kind of offshoot species or subspecies entails, if only for a geological moment, the prior existence of a geographically or similarly isolated form. In practice the innumerable examples of such intermediates tend to be grouped with the ancestral or the new species or to be listed as 'transitional forms'. On the geological time-scale in fact geographical subspecies are so ephemeral that the importance ascribed to them in neontology appears to us to be somewhat exaggerated.

There is much argument about types of isolation that are necessary and effective for the establishment of species. Mayr emphasises always the necessity of physical separation by a physical barrier of two or more parts of an existing species before new subspecies or species can branch off it. The first problems that result from this assumption are ones of terminology. Some writers maintain the necessity of geographical isolation, but there are many types of spatial isolation, particularly in the sea, which are not reasonably described as geographical. We know rather little of what constitutes isolation in the sea. For many species there are critical temperatures above or below which they cannot reproduce. A steep temperature gradient therefore operates as an isolating mechanism for such forms as effectively as does a land-mass between two seas. Off Greenland there is

spatial zoning of the plankton off the glaciers as a result of the rising to the surface of cold glacier meltwater.¹ The common octopus is at the limit of its temperature endurance in the English Channel and only in unusually warm seasons can it spread to the north of the Channel and thereby become a temporary pest to the crab and lobster industry. Although deep-sea dredging has disclosed limited areas densely populated with sessile organisms, we do not know what are the factors that limit the spread of these areas. In some cases it is probably a question of suitable bottom or currents or temperature but there may be many other things that serve to break up the total population of a species into separate isolated fragments that effectively breed only among their own members.

Animals with long-lived pelagic larvae, planktonic or nektonic, must inevitably have a more random distribution than forms reproducing by budding or breaking off of fragments or by eggs that are deposited on the bottom. Although much is known in detail about the breeding habits of many marine invertebrates there is a lack of integrated accounts of the total biology of most of them.

Likewise we know far too little about marine distribution, especially of benthonic forms. The tale of the imperfection of the geological record is a hackneyed one, but in particular cases of missing evidence we can never tell whether it is due to geological 'imperfection' or to a changing distribution of the species that we are seeking. In this connection it is instructive to consider rarities, a class of species seldom examined in any general discussions. *Echinothuria floris* Woodward, the first post-palaeozoic flexible sea-urchin to be discovered, was known to its author by two specimens from the Upper Chalk. Three or four more have been found since, but that is all. There are no Cainozoic members known of the family to which this species belongs, yet members of it are widespread in the oceans today. *Hyposalenia paludensis* Lambert is known by one specimen from southern France and one from Leighton Buzzard. These and many other examples that could be quoted are due mainly no doubt to a combination of collection failure and the imperfection of the geological record. But similar examples are well known among living species. Readers of the story of the Kontiki expedition will be aware of the large number of previously little known fishes and other creatures that were encountered. The recent Galathea deep-sea expedition came across a number of animals in the Philippine and Banda trenches that were known before only from the Arctic. We must clearly be continually on our guard against arguing from negative evidence in all matters of distribution. In any case our ignorance of the basis of and the factors affecting the distribution today of rare species in the seas is almost complete: still greater is our ignorance of the

¹ I owe this example to Group Captain C. A. Hartley.

past. Yet the rarity of one day may be the ancestor of a flourishing and widespread stock.

I have elsewhere criticised neontologists for ignoring the element of time in classification. The currently popular definition of a species as a 'potentially interbreeding population' gives point to the criticism. A species has a beginning and an end in time; except in the case of extinction without leaving descendants, both of these must be arbitrary. There is no means of testing whether the early and late members of a species that is universally recognised as such could interbreed and it is most unwise therefore to treat interbreeding as an essential criterion of species. Just as species may vary widely in space, so they may in time, and the type-specimen of a species may be uncharacteristic of the whole in temporal as in geographical variation. The neontologist can survive without recognising all this but the palaeontologist cannot and the latter seems consequently to me to have inherently a better chance of taking a proper view of classification and the best line between splitting and lumping.

In this connection I must quote the case of the dichotomous key. However useful for the identification of species the key tends to be not only a symptom but to some extent a cause of the lack of phylogenetic thinking in classification. Keys over-emphasise characters that are in fact trivial so far as the history of a genus or family goes and give a dangerous appearance of fixity and rigidity in taxonomy.

It is particularly interesting to consider what happens when a species begins. One should first of course look at present-day occurrences. Unfortunately, while there are a certain number of good examples of incipient speciation described from plant and land animals, there is comparatively little known about marine invertebrates. I explained that in any case where a subspecies is leading to a full species by a process of branching off the main stock, there must somehow be isolation to interrupt the gene flow and consequently there must, in theory, be geographical subspecies. There cannot, however, be any readymade objective way of deciding when one passes from one species to another. The decision is easier in cases of 'branches off' from one stock, for it is possible to compare an isolated new species with contemporary examples of the main stock in the old area. Where on the other hand speciation is occurring by what is virtually, in geological time, conversion of the whole stock, discrimination is particularly difficult. There are those palaeontologists who maintain that any separable form that is distinguished chronologically should be made a distinct species. This reflects the old idea of d'Orbigny that the examples of a single lineage in successive geological stages must be different species. In contrast to this view is that of the many palaeontologists who are so impressed by the continuity of a slowly changing stock that they cannot bring themselves to carve it up into separate species at all. In any particular

biological group one is liable to change from one attitude to another in the light of the information available and the degree of study that it has received.

In the main seas represented by the Upper Chalk of North-Western Europe there are many examples of slow and continuous change in various invertebrate groups which pose problems of the type we have been discussing. In the various lineages of starfish of the families *Pentagonasteridae* and *Pentacerotidae*, there has been described a series of changes in a variety of characters which seem to have occurred in the same succession in parallel stocks. While many of these characters were no doubt the result of random variations fixed in a small part of the population that was temporarily isolated and then spread again through the whole population, others seem to be the result of a steady pressure of a uniform environment on lineages whose capacity to vary was much the same and which responded in the same way. In such a case the problem of where to draw the line between species is difficult. Either one can treat the whole of a lineage as a cline in time and reach the ridiculous position of the early and late forms being totally unlike one another, or one is compelled to pick on arbitrary points in the series. The same sort of problem arises in the well-known case of the *Micraster* of the Upper Chalk. Kermack has recently demonstrated that three forms that occur in succession in the Turonian and Coniacian, *leskei*, *praecursor* and *cortestudinarium*, have differences in shape and proportions which are only expressions of allometric growth. For example, any *praecursor* that grew big enough would be a *cortestudinarium*. However, at some horizons no examples of *praecursor* are found that do grow big enough. Size, I have little doubt, was in these cases genetically controlled. Moreover, size and shape in this way can be coupled with the stages of development of the well-known progressive characters in ornament and in the ambulacra, which have been described by Rowe, and good specific distinctions can be made.

How do species begin in the sea? In principle there is presumably no difference from what happens on land. Isolation in the trenches of the deep sea and in the bays of shallow seas is easy enough to understand. Many circumstances, for example changes of temperature and salinity, could allow intermittent colonisation by a species of new areas which were subsequently isolated by a reversal of circumstances. In the cases of the inhabitants of the deep trenches discovered by the Galathea Expedition, it is easy to see how the cold waters of the deepest abyssal trenches might contain a variety of species characteristic of Arctic waters which have been isolated from each other by a slight change in the general temperature of the oceans. The development of new species in a particular trench then becomes perfectly possible. The same sort of thing can happen with benthonic organisms in areas of changing bottom conditions, if the species

are tied to a particular type of bottom and also if the species breeds on the site and does not, as do so many marine organisms, reproduce wastefully from vast numbers of pelagic larvae.

Even in the apparently uniform deep ocean waters many sessile organisms seem to live in isolated colonies. Moreover, many bathypelagic higher organisms live in schools, for example some squids and fishes, kept together perhaps by luminescent organs.

Despite, therefore, the apparent greater uniformity of sea floor and water conditions compared to land surfaces, it is easy to postulate plenty of isolating factors to allow the separation of new forms from old by the spread in a limited population of new recessive genes.

Granted then speciation in the standard way by the drifting or pushing of whole populations and by isolation of parts of populations, we are faced, from the point of view of the taxonomist, with problems of nomenclature and discrimination of species. In fact in the literature more is made of the problems of describing what happens than of finding out what happens and how it happens. These latter questions, which after all are the ones which really matter, cannot be solved by reading books. They need on one side prolonged study of what goes on in the seas today, and on the other the accumulation of detailed studies by palaeontologists of the appearance and disappearance of successional species, of bursts of evolutionary radiation, and of the innumerable cases of the production of offshoot species. Without evidence and description of what has happened in the past, the most profound studies by neontologists of what might happen to species in time and space are unlikely to carry conviction.

Finally, in an attempt to clarify the type of development which I believe is normal, I will attempt to describe an imaginary burst of evolutionary radiation in a stock of marine invertebrates inhabiting shallow offshore waters.

Imagine the west coast of a large land-mass straddling the Equator and lying to the south of part of the Mesozoic Tethys. Let us suppose that this west coast is partly bathed in a north-flowing current of cold water from the Antarctic depths, that a large river debouches in a bight, to the north and south of which are prominent capes.

The effect of this large river will be to lay down muddy deposits for a considerable distance offshore and to reduce the salinity of the water for some distance from the coast. The effects of the cold water current flowing towards the north will be to imprison near the coast, in places at any rate, patches of warm water derived from a reverse flow inshore from the Tethys.

With these varying factors as background, imagine the arrival by migration from the Tethys of a new stock of animals with pelagic larvae and requiring fairly warm waters for development. During a period when the reverse flowing warm current was of some strength, this stock might

spread far down the coast that we are considering, perhaps as far as the area of reduced salinity off the mouth of the large river. Then the cold current moves closer inshore. For all practical purposes the population of our animal is divided up in the various bays of the coast, since its pelagic larvae cannot develop in the colder water flowing a little way offshore. In a comparatively short time, geologically speaking, each of these isolated parts of the population may develop in a slightly different direction producing distinct species. With a reversal of the isolating mechanism these species will then spread north and south until they are living sympatrically over the whole of the coast-line.

Imagine a slight change in the climate of the land-mass resulting in a much reduced flow by the large river. A single one of the present group of species perhaps manages to migrate past the barrier represented by the fresh water poured out by the river. This species perhaps is now preadapted to existence in cooler waters and spreads widely therefore in the area to the south. In course of time the whole of this subsidiary stock may come to depend on waters of the temperature prevalent in the southern area. Depression in part of the land-mass might result in a counter-flow from its eastern part of warm water which would supply the same sort of isolation in embayments, but in the reverse sense, as has been described for the northern part, with consequent opportunities for speciation. The resulting group of species might in due course under changing circumstances migrate northwards again and provide another contribution to a single fauna.

Thus without any interposition of 'ecological speciation' it is possible to envisage in a short space of geological time, the production of a wide variety of species from a single fauna as a result of selection pressure in areas isolated by simple mechanisms that are widespread in the seas. The example just given takes no account of many other environmental or isolating factors which both complicate the picture and provide more abundant opportunities for speciation. Geology may not be able to provide detailed, illustrated and demonstrated examples of the formation of a particular species in a particular spot, but it certainly can give a generalised picture of the type of speciation that obtains and of the conditions which induce it.

Lower Gault Sections in the Northern Weald and the Zoning of the Lower Gault

by H. G. OWEN

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ABSTRACT: The section in the Lower Gault exposed at the Buckland Sand and Silica Company's pit at Buckland, Surrey, is described, and a recent description of the Lower Gault at Greatness, Sevenoaks, is reviewed. A correlation is made between the sections exposed at Buckland, Dunton Green and Greatness, and the Lower Gault exposed at Copt Point, Folkestone. The Folkestone section is discussed in the light of recent work, and it is shown that in the northern Weald the principal bed of phosphatic nodules in the *dentatus-spathi* Subzone is of later date than the *dentatus*-nodule bed in Bed 1. Accompanying the marked attenuation of the *lautus* Zone in northern Kent, there is an expansion of the equivalent of Bed IV of the Folkestone section. It is shown, however, that beneath the '*lautus* Zone nodule bed' at Greatness, deposits of undoubted *lautus-nitidus* Subzone age occur. The zonal classification of the Lower Gault is reviewed. The upper limit of the *dentatus-spathi* Subzone is defined to include deposits containing *Hoplites escagnollensis* which occur below the horizon of *Anahoplites intermedius*. It is suggested that the *subdelaruei* Subzone, recently included in the *niobe* Subzone, should be retained separately.

1. INTRODUCTION

THROUGH the detailed work of Dr. Spath on the Ammonoidea of the Gault (1923-43), especially on the stratigraphical ranges of the ammonite species, it has been possible in more recent years to determine accurately the zonal stratigraphy of the Gault. Since the completion of his Monograph, the opening of fresh brick-pits in the Gault, together with further collecting, has provided much new information. Spath's broad review of the stratigraphy (1943, 734) can now in part be amplified.

The Gault of the Weald has attracted the attention of many workers, and much has been written about it. The classic Folkestone section in particular has been studied in detail, notably by De Rance (1868), Price (1879), Jukes-Browne (1900), and Spath (1923b, 1925b, 1926b), and these are but a few of the many papers written on different aspects of the Folkestone Gault. Accounts of sections exposed in inland areas of the Weald have been published and many of these have appeared in the PROCEEDINGS. It would seem therefore that the detailed stratigraphy of the Gault in the Weald is well known, but this to a degree is not so. One only has to check a list of the brick-pits worked in the Gault during this century to realise that many of them have been only briefly mentioned in papers, and in some cases not at all, whilst but a few sections have been described in detail. Even at Folkestone in recent years, much further information has come to light.

Jukes-Browne in 1900 reviewed in detail the stratigraphy of the Gault, describing or redescribing the sections exposed at, or before, that date. At the present time, in north-west Kent there are three brick-pits in work showing sections in the Lower Gault. These are situated near Trottiscliffe, Greatness and Dunton Green. At Buckland, in Surrey, there is an exposure of the Lower Gault in the extensive workings of the Buckland Sand and Silica Company. In this paper, the section exposed at Buckland is described for the first time, whilst the section at Greatness, recently described by Milbourne (1956, 235–42), is revised. The correlation between the sections exposed at Buckland, Dunton Green, Greatness and Folkestone is discussed in detail, in the light of new information. The section of the Gault exposed near Trottiscliffe is not discussed here as this is to be the subject of a separate paper by Casey & Milbourne.

2. DESCRIPTION OF SECTIONS

(a) Buckland

(i) *Introduction.* Owing to the paucity of exposures in the Gault of the Reigate area, little is known of its detailed stratigraphy. Gossling described the known exposures of the Gault (1929, 247–51), demonstrating the absence of the *lautus* Zone. The Geological Survey Memoir (1933) recorded further information.

The Lower Gault has been exposed for some years in the large sand-pit owned by the Buckland Sand and Silica Company, which lies approximately 1050 yards ENE. of Buckland Church, and about 350 yards north of the main Reigate–Dorking road (A.25), Buckland, Surrey (25/231512). At the western end of the pit, a section is exposed extending from the middle of the Folkestone Beds to the clays of the *niobe* Subzone of the Lower Gault. The Gault–Lower Greensand junction beds and the Upper

Folkestone Beds are not described here, but a brief description of them was given by Kirkaldy in 1947 (192-3).

(ii) *Description.* The Lower Gault varies in thickness and lithology around the western end of the pit. The following is a section in the northern face where the development is relatively thick.

Subzone	Bed	Lithology	ft.	in.
		Overburden of drift		
<i>Dimorphoplites niobe</i>	13.	Mottled brown and blue-grey clay with a line of crushed lamellibranchs at the base	2	0
	12.	Light grey clay	3	3
<i>Anahoplites intermedius</i>	11.	Very dark brown clay	4	0
	10.	Dark blue-black clay with yellowish patches	3	0
	9.	Highly ferruginous yellow clay with thin stony lenticles		7
	8.	Dark grey clay	4	0
	7.	Impersistent lenticles of ferruginous marlstone		4
<i>Hoplites dentatus</i> and <i>Hoplites spathi</i>	6.	Hard brownish marly clay with marly seams	4	0
		passing down into:		
	5.	Dark grey clay with marly seams, slightly mottled about	2	0
	4.	Bed of phosphatic nodules		1 to 4
<i>Hoplites benettianus?</i>	3.	Clay with pockets of glauconite and scattered phosphatic nodules	3	3
	2.	Line of scattered subangular phosphatic nodules, mainly abraded fragments of <i>Hoplites</i>		2
	1.	Gritty glauconitic clay with patches of glauconite sand	1	6
Gault-Lower Greensand Junction Beds				

A diagrammatic vertical section of the Lower Gault exposed in this pit is given (Fig. 1). Lateral variation in lithology and thickness is shown, for example, by Beds 6 to 9, which consisted in 1951 of irregular lenticles of brick-red marl in a mottled grey marly clay. As the section was cut northwards away from the feather-edge of the outcrop, thin irregular lenticles of ferruginous marlstone appeared, whilst the clays thickened. In 1957, there were two persistent bands of ferruginous marl (Beds 7 and 9) which contained lenticles of marlstone. These beds, together with Bed 5, attenuate markedly when traced towards the edge of the outcrop.

Evidence of disturbance within the Gault is shown by marked rucking in the beds from 4 upwards, whilst the more plastic clays of Bed 5 show slickenside features. When the northern face of the pit to the east of the

Gault section was cleared, a section was exposed which consisted of about twenty feet of alternate layers of sand and clay with subangular lumps of flint, adjoining on the western side slightly disturbed Folkestone Beds and *mammillatum* Zone nodule beds. The Gault on this eastern side near this slip section is disturbed. Small exposures of the basal clays of the Gault can be seen above the Gault-Lower Greensand Junction Beds along the northern face of the workings, and especially at the extreme east end of the pit. The dip of the beds is about 8° towards the NNW.

(iii) *Classification*. Bed 1 is apparently unfossiliferous, but the line of subangular phosphatic nodules of Bed 2 contains fragmentary abraded ammonites, amongst which *H. cf. bullatus* Spath has been recognised indicating the *benettianus* Subzone, to which this bed is provisionally referred.

The *dentatus-spathi* Subzone is represented in Beds 3 to 6. Scattered phosphatic nodules occur throughout the clays of Bed 3 and yield fragmentary examples of *Hoplites*, including *H. dentatus* (J. Sowerby). Bed 4 is the most fossiliferous horizon exposed in the pit, and has yielded an ammonite fauna, well preserved in phosphate, indicating the upper part of the *dentatus-spathi* Subzone. The ammonites include:

Hoplites dentatus (J. Sowerby) and its varieties *densicostata* Spath (late form), and *sulcata* Seitz, *H. aff. dentatus* evolute variety, *H. aff. spathi* Breistroffer (late mutation), *H. rudis* Parona & Bonarelli, *H. aff. paronai* Spath, *H. canavarii* Parona & Bonarelli, *H. aff. canavariiformis* Spath, *H. vectensis* Spath, *H. dorsetensis* Spath, *H. latesulcatus* Spath, *H. persulcatus* Spath, *H. similis* Spath, *H. aff. escragnollensis* Spath, *H. aff. mirabilis* Parona & Bonarelli, *H. spp.*, *Euhoplites* spp. (transitional from *Hoplites*), *Pictetia astierianum* (d'Orbigny), *Oxytropidoceras roissyanum* (d'Orbigny), *Hamites* spp. Casey (1957, 35, pl. 7, fig. 12) has figured an example of *Eubrancoceras* from this horizon.

Crushed impressions of ammonites, distorted by movement of the clays, occur sporadically throughout Bed 5 and the lower part of Bed 6. A few inches beneath Bed 7 there occurs a thin seam of crushed pyritic impressions of ammonites which appear to be species of *Hoplites*.

Beds 7 to 11 are classified with the *intermedius* Subzone. The crushed impressions of fossils in these beds are covered with a thin film of pyrite which has replaced the original calcareous shell. Where determinable ammonites occur, especially in Bed 8, they consist mainly of species of *Anahoplites*, such as *A. intermedius* Spath, and *A. praecox* Spath, whilst *Euhoplites loricatus* Spath occurs sparingly. Bed 8 has also yielded *Protanisoceras cf. nodosum* (J. Sowerby).

Whether Bed 12 should be classified with the *niobe* Subzone has still to

be confirmed, for, like Bed 11 below, the original pyritic material in these clays has decomposed and the little patches of selenite crystals which occur probably mark the former position of crushed fossils. Bed 13 has yielded ammonites which indicate the *niobe* Subzone, such as *Dimorphoplites* cf. *niobe* Spath, *Anahoplites planus* (Mantell), *A. splendens* (J. Sowerby), *Euhoplites loricatus* Spath, *E. aff. subtuberculatus* Spath, and *Hamites* spp. One crushed impression of a *Dimorphoplites* from this bed is referable to a new species of *Dimorphoplites* which is known to occur in the lower nodule bed of Bed IV at Folkestone. It is possible, therefore, that the *subdelaruei* Subzone might be represented in this Bed 12, but as yet no specimens of *Mojsisovicsia* have been found.

The clays above Bed 4 are mainly disturbed and weathered, and at this time yield only crushed or partly uncrushed ammonites, and most of these are poorly preserved. The overlying drift contains occasional patches of pale grey clay which have yielded Upper Gault fossils.

(b) Greatness Lane (revised)

(i) *Introduction.* The section in the Lower Gault exposed at the Sevenoaks Brick Works Limited pit (55/536578) at Greatness Lane, Sevenoaks, has recently been described in some detail by Milbourne (1956). Some variations have been detected between the section described by him and that examined by the author. As the bulk of the *lautus* Zone nodule bed in the worked southern face of the pit might be quarried away within the next few years, it seems advisable to discuss some of the results obtained by the author. Detailed lithological subdivision of a highly variable formation such as the Gault should be carried out with caution especially when this subdivision cuts across the broad lithological features.

(ii) *Description.* At the Sevenoaks Brick Works pit, and elsewhere in NW. Kent, the Lower Gault can be divided into six broad lithological divisions. The figures given in parentheses refer to bed numbers used by Milbourne.

Division	Lithology	ft.	in.
6.	Prominent band of phosphatic nodules containing 'derived' and indigenous fossils, ' <i>lautus</i> Zone nodule bed' (18)		2 to 6
5.	Blue-grey clay with brownish patches becoming fawn-grey at the base, which is marked by incipient lenticles of ferruginous marly clay (17)	6	6
4.	Broad-banded clay, alternating dark-grey clay and lighter fawn-grey marly clay containing lenticles of hard ferruginous marlstone, more prominent at base (9)	8	0
3.	Dark grey clay (3-8) about	18	0
2.	Line of black phosphatic nodules mainly casts of species of <i>Hoplites</i> , with portions of the shell remaining (2)...		1 to 2
1.	Dark grey clay becoming a little lighter below (1) measured to	3	6

Phosphatic nodules occur throughout, and at certain levels distinct lines of nodules might be made out. Shell seams are numerous, but few of them are of any lateral extent. A diagrammatic vertical section of the Lower Gault at Greatness Lane is given in Fig. 1.

The section is worked by multi-bucket excavators on two faces, both on the southern side, separated from each other by a shelf upon which the excavators are mounted. The general dip of the strata in the area is towards the north at an angle of about 4° to 5° . In this pit, however, there is a pronounced east-west dip marking a tectonic feature. When viewed from the north the divisions in the southern face are seen to dip sharply at the western end of the workings. This sudden dip in the east-west direction together with the observed northerly dip of 4° causes Divisions 5 and 6 to be exposed in the lower face at the western end of the pit.

(iii) *Classification*. Since July 1957, the clays of Division 1 have been exposed to a depth of three feet six inches. They consist of highly fossiliferous dark grey clay with crushed ammonites. In the upper ten to twelve inches these belong to species of *Hoplites* including *H. dentatus* (J. Sowerby), and *H. persulcatus* Spath, together with occasional specimens of *Hamites*, and are classified with the *dentatus-spathi* Subzone. Division 2 contains an ammonite fauna indicating the upper part of the *dentatus-spathi* Subzone, and is overlain by about two feet of dark grey clay, at the base of Division 3, which contains crushed impressions of species of *Hoplites*, some with conspicuous lautiform ribbing. Milbourne (1956, 239) correctly placed the nodule bed in the *dentatus-spathi* Subzone, but at least two feet of the overlying clays (part of his Bed 3) classified by him with the *intermedius* Subzone should also be included in the *dentatus-spathi* Subzone, since *Anahoplites intermedius* Spath first appears at about two feet nine inches above the nodule bed.

The bulk of the remaining fifteen feet of Division 3 is referred to the *intermedius* Subzone (Casey, 1954, 265), whilst a conspicuous line of ammonite body chambers which occurs some three feet beneath the base of Division 4 has also yielded *Anahoplites mantelli* Spath and a very coarse evolute form of *Anahoplites praecox* Spath previously known from the corresponding horizon at Dunton Green and now also known from the nodule bed in the middle of Bed II at Folkestone. Continued collecting may show this horizon to be an important datum level in the *intermedius* Subzone.

Milbourne records the occurrence of *Mojsisovicsia subdelaruei* (Spath) twelve feet four inches beneath the *lautus* Zone nodule (in his Bed 10), two feet two inches above the base of Division 4. The author has obtained an example of *M. remota* (Spath) from six inches below the top of Division 4, about five feet four inches above the previous record of this genus. The inclusion of the *subdelaruei* Subzone in the *niobe* Subzone by Milbourne

(1956, 241) is not accepted here. Reasons for the retention of a separate subzone of *Mojsisovicsia subdelaruei* are given below. The clays of Division 4 from a level two feet two inches above its base are classified here with the *subdelaruei* Subzone, whilst the lower two feet two inches and probably the extreme top of Division 3 are classified with the restricted *niobe* Subzone.

At the base of Division 5 there is a sharp change in the colour of the clay associated with small lenticular patches of highly ferruginous marly clay. Crushed fossils consisting mainly of *Inoceramus concentricus* (Parkinson) occur throughout the lower part until a level three feet seven inches beneath the *lautus* Zone nodule bed is reached. At this level there occurs a line of partly phosphatised ammonites still retaining the shell, but with the inner whorls obscured by limonitic ochre. This bed has yielded *Euhoplites loricatus* Spath (late mutation), *E. meandrinus* Spath and large *Anahoplites planus* (Mantell), amongst other ammonites which occur in the upper nodule bed of Bed IV and the base of Bed V at Folkestone discussed below. The late mutation of *E. loricatus* ranges up to within one foot five inches of the top of Division 5. Between two and three inches beneath the top of Division 5 there occurs a line of partly phosphatised ammonites including *Euhoplites* in which the typical channelled venter of the *Euhoplites* of the strict *lautus* Zone is well established. These species of *Euhoplites* occur definitely below the base of Division 6, the *lautus* Zone nodule bed, and are associated with other ammonites of the *lautus-nitidus* Subzone. The clays of Division 5 from a level three feet seven inches beneath the *lautus* Zone nodule bed, up to a level four inches beneath it, are classified with a distinct but as yet unindexed subzone which was included by Spath in the *subdelaruei* Subzone. This horizon is not included here in the *lautus-nitidus* Subzone (Milbourne, 1956, 241). The upper four inches of Division 5 contains *Euhoplites lautus* (Parkinson MS.) J. Sowerby and varieties, *E. nitidus* Spath, *E. aff. truncatus* Spath, *E. proboscideus* (J. Sowerby), together with species of *Anahoplites* and *Dimorphoplites*, and are thus classified with the *lautus-nitidus* Subzone, the lowest subzone of the restricted *lautus* Zone.

Species of *Euhoplites* indicating the *lautus-nitidus* Subzone occur in Division 6, but they are usually, but not always, in possession of the shell, and are in direct contrast to the ammonites preserved in hard, very dark brown to black phosphate which are usually abraded and do not possess the original shell on exposed surfaces. Apart from the ammonite fauna listed by Milbourne (1956, 237-8) there occur, preserved in hard dark brown phosphate, *Anahoplites daviesi* Spath and its variety *ornata* Spath, together with an extreme form found in the uppermost few inches of Bed VII at Folkestone, which appears to connect directly with *Epihoplites*. Other ammonites transitional between species occurring in the *daviesi* Subzone and those found in the *cristatum* Subzone also occur in Division 6.

This bed also contains a large number of ammonites which are known to occur in the *cristatum* Subzone at Folkestone. The occurrence of a number of 'indigenous' partly crushed ammonites of definite *cristatum* age at Greatness and in equivalent horizons elsewhere is of importance for it helps to place the relative date of the disturbance which caused the condensation and westerly removal of deposits of *lautus* Zone age. Division 6 therefore contains an ammonite fauna indicating part of the *lautus-nitidus* Subzone, the *daviesi* Subzone, and the *cristatum* Subzone.

3. CORRELATION

(a) Between the Sections at Greatness and Copt Point, Folkestone

From the few relatively uncrushed ammonites seen in the upper foot of the clays of Division 1 at Greatness, these deposits appear capable of correlation with the *dentatus*-nodule bed in Bed I at Copt Point, Folkestone. This nodule bed contains a fauna in which the typical *Hoplites dentatus* (J. Sowerby) is common. It also contains specimens of *Hoplites* which are transitional from those occurring in the *benettianus* Subzone, absent from the Folkestone succession (Spath, 1935b, 430; Casey, 1950, 275). An example of one of these transitional types collected by the author possesses prominent umbilical tubercles together with a ventrally depressed whorl section and is transitional between the *Hoplites* aff. *paronai* figured by Spath (1925, pl. XI, fig. 1) and *Hoplites benettianus* (J. de C. Sowerby).

The correlation of Division 2, the upper *dentatus-spathi* nodule bed, at Greatness with the whole of the upper part of Bed I at Folkestone (Milbourne, 1956, 240) is questioned here. About two feet six inches of the clays at the top of Bed I at Folkestone contain crushed and partly uncrushed ammonites, chiefly species of *Anahoplites*, including *A. intermedius* Spath and *A. praecox* Spath, and therefore belong to the *intermedius* Subzone. The five feet of clays below contain crushed species of *Hoplites*, which in the upper part are closely comparable, from the lateral aspect, with ammonites which occur uncrushed in Division 2 at Greatness and especially in Bed 4 at Buckland and equivalent horizons elsewhere. However, neither *Anahoplites intermedius* nor *A. praecox* occur in the upper *dentatus-spathi* nodule bed at Greatness or at Buckland, and appear only at a height above the nodule bed, and above clays which also contain species of *Hoplites*. At Greatness, *A. intermedius* appears at about two feet nine inches above Division 2 and thus in the revised correlation proposed here, Division 2 and the lower part of Division 3 to a height of two feet nine inches are correlated with the lower five feet of clays at the top of Bed I at Folkestone.

The remainder of Division 3 may be correlated with the upper two feet six inches of Bed I, and Bed II at Folkestone. The tentative correlation

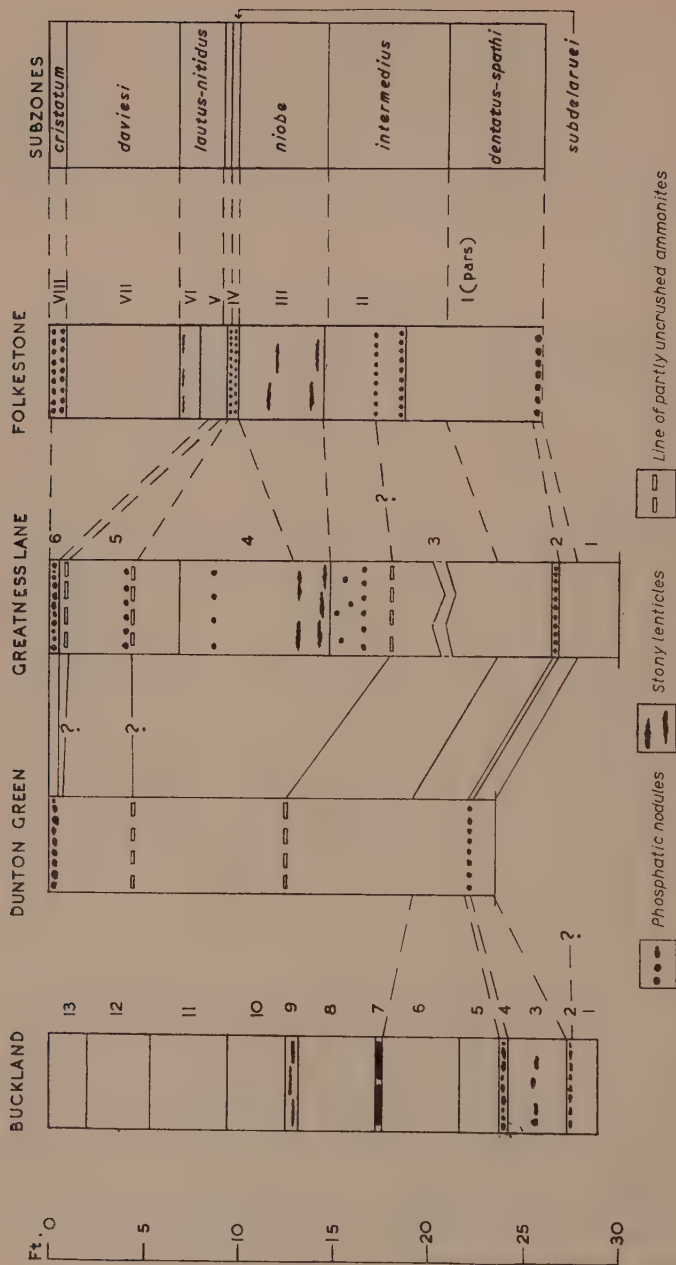


Fig. 1. Vertical sections of the Lower Gault at Buckland, Duntun Green, Greatness and Folkestone

between the line of uncrushed ammonite body chambers three feet beneath the top of Division 3 and the line of phosphatic nodules in the middle of Bed II appears to be supported by the distribution of *Euhoplites pricei* Spath, the typical form of which occurs in the upper part of Bed II above the nodule bed. At Greatness, *E. pricei* occurs above the line of uncrushed body chambers in the uppermost part of Division 3 (Milbourne, 1956, 238).

The lower two feet two inches of Division 4 contains *Dimorphoplites niobe* Spath, but species of *Mojsisovicsia* are absent. These clays contain lenticles of marlstone, and are similar in character to the clays of Bed III with which they are correlated. There is thus an attenuation of deposits belonging to the restricted *niobe* Subzone at Greatness when compared with the Folkestone section.

At Greatness, the *subdelaruei* Subzone is about eight feet nine inches thick in comparison with about six inches of Bed IV at Copt Point, Folkestone. At Folkestone, Bed IV consists of (i) a line of crushed shells about one inch in thickness with usually buff coloured phosphatic nodules, overlain by (ii) about four to five inches of grey clay, which is in turn overlain by a bed of black phosphatic nodules between one and two inches in thickness (iii) containing abraded fossils in a matrix of grey clay. Species of *Mojsisovicsia* occur in (i) and (ii), but as yet no species of *Mojsisovicsia* have been found in the upper nodule bed (iii) of Bed IV, or its lateral equivalents elsewhere. Milbourne noted the occurrence of *Dimorphoplites niobe* Spath in his beds 8 to 11 at Greatness and thus considered that the band of crushed shells (10) in which he obtained *M. subdelaruei* was well within the *niobe* Subzone. It must be noted, however, that the typical *D. niobe* also occurs at Folkestone in the lower part of Bed IV having ranged up from the top of Bed I.

Bed IV (iii) at Folkestone, the upper line of nodules, contains abraded, phosphatised, usually fragmentary ammonites which bear witness to the removal of some thickness of sediment before they were deposited together in a single one to two inch nodule bed. The ammonites include:

Anahoplites planus (Mantell), *A. splendens* (J. Sowerby), *A. pleurophorus* Spath, *Dimorphoplites pinax* Spath, *D. doris* Spath, *D. aff. niobe* Spath, *D. tethydis* (Bayle), *Euhoplites aspasia* Spath, *E. loricatus* Spath (late mutation), *E. subtuberculatus* Spath (late mutation), *E. meandrinus* Spath, *Hamites attenuatus* J. Sowerby, *H. rotundus* J. Sowerby, *H. aff. tenuicostatus* Spath, *H. gibbosus* J. Sowerby.

The basal few inches of Bed V contains a similar fauna but with a number of examples of *Euhoplites* such as *E. aspasia* var. *cantiana* Spath, which are transitional to the typical *E. lautus* (Parkinson MS.) J. Sowerby and its allies of the restricted *lautus-nitidus* Subzone. The clean-cut ventral groove

of the species of *Euhoplites* characteristic of the *lautus* Zone is not generally developed in the few inches of clay at the base of Bed V. *E. meandrinus* Spath, originally proposed as a variety of *E. loricatus* (1930, 271), appears to be restricted to the top of Bed IV and the base of Bed V.

At Greatness, the lateral equivalents of Bed IV (iii) and the base of Bed V are about two feet five inches thick, and are represented within Division 5 from the line of partly phosphatised ammonites which occurs three feet seven inches beneath the top of the division up to a similar line of ammonites four inches beneath the top.

The upper four inches of Division 5 may be correlated with part of Bed V at Folkestone classified with the *lautus-nitidus* Subzone. At Folkestone, the *lautus-nitidus* Subzone embraces the remainder of Bed V and the whole of Bed VI. Apart from the ammonites listed by Spath (1942, 674-81), there occurs in Bed V a coarsely ornamented species of *Anahoplites* similar to the 'mutatio ascendens ad *A. daviesi*' figured by him in 1926 (153, pl. XIII, fig. 9). It differs from *A. daviesi* by possessing finer ornament and by lacking the typical excentric umbilicus. In Bed VI the coarsely ornamented *Dimorphoplites parkinsoni* Spath is a characteristic species.

Milbourne has reported that there was no certain evidence for the correlation of Beds VI or VII with the *lautus* Zone nodule bed, Division 6 (his Bed 18, 1956, 241). Indeed, typical *Dimorphoplites parkinsoni* has not been found, but a closely allied form has been collected by the author. It has been mentioned above that Division 6 has yielded *Anahoplites daviesi* and its variety *ornata*. Collecting from Bed VII at Folkestone suggests that the typical *Anahoplites daviesi* occurs in its upper part, together with the variety *ornata* (compare Spath, 1925b, 34-5). The extreme form of *A. daviesi* also found in Division 6 at Greatness occurs at Folkestone in the clays at the extreme top of Bed VII, usually in a crushed or partly crushed condition. A closely similar form was referred to by Spath (1926, 153).

Ammonites of the *cristatum* Subzone occur in Division 6 in two modes of preservation: (a) as dark brown partly abraded casts in phosphate without traces of the shell, and (b) as completely or partly phosphatised casts still retaining the shell with some portions of the ammonite crushed flat. These ammonites include species which occur in the upper nodule bed of Bed VIII at Folkestone. Division 6 may therefore be correlated with Beds V (part) to VIII of the Folkestone section.

Milbourne has correlated the blue-grey mottled clays to a height of three feet eleven inches above the *lautus* Zone nodule bed at Greatness with the upper nodule bed of Bed VIII, but at a height of one foot four inches above the nodule bed *Neophlycticeras brottianum* (d'Orbigny) has been obtained. This species is considered to be of *orbigny* Subzone age and occurs in Bed IX at Folkestone. It should be noted that the lowest part of Bed IX at Folkestone contains large crushed species of *Euhoplites*,

Anahoplites, *Epihoplites* and occasional *Dipoloceras* and *Beudanticeras* amongst others, but *Hysterocheras* is rather uncommon at this level.

(b) Between the Sections in the Northern Weald

The correlation of the sections exposed at Buckland and Dunton Green with the section at Greatness is shown in Fig. 1. Owing to the weathered and disturbed nature of the upper beds of the Lower Gault above Bed 4 at Buckland, the correlation of these deposits with the sections exposed in the Sevenoaks area will not be attempted here.

The *benettianus* Subzone is probably represented in part in Bed 2 at Buckland and possibly also in the exposed lower part of Division 1 at Greatness. Deposits of undoubted *benettianus* age have been recorded from the Oxted area (Wright & Wright, 1948, 86), and have been found elsewhere in the northern Weald.

The section exposed at the Dunton Green Brick, Tile, and Pottery Company's pit (55/515570) has been described by Wright (1947, 315-18) and briefly mentioned by Casey (1954, 265). The *dentatus-spathi* Subzone is represented within the one foot six inches of dark grey clay containing crushed species of *Hoplites* of the *dentatus*-group, exposed above the base of the pit, and in the overlying one to two inch-thick bed of black phosphatic nodules ('Bed 1 nodules') with phosphatised fragments of species of *Hoplites* indicating the upper part of the *dentatus-spathi* Subzone. This in turn is overlain by about six inches of dark grey clay containing *Hoplites eschagnollensis* Spath, together with a number of crushed ammonites referable to *H. dentatus* var. *densicostata* Spath. *Anahoplites intermedius* is first met with about two feet nine inches above the Bed 1 nodules. This first appearance of *Anahoplites intermedius* is considered here to mark the base of the *intermedius* Subzone.

At Buckland, the *dentatus-spathi* Subzone is represented within Beds 3 to 6. Bed 3 may be correlated with the one foot six inches of dark grey clay below the Bed 1 nodules at Dunton Green, and with the upper ten to twelve inches of clays in Division 1 at Greatness. Bed 4 at Buckland is on the same horizon as the upper *dentatus-spathi* nodule bed in the Sevenoaks area. This bed has been located in the Metropolitan Water Board's well at Brasted (Casey, 1954, 266), and is represented by the 'Bed 1' nodules at Dunton Green and by Division 2 at Greatness. Beds 5 and 6 at Buckland are probably represented in part only by the six inches of clays overlying the Bed 1 nodules at Dunton Green and the lower two feet of Division 3 at Greatness. It must, however, be noted that the ammonites in Beds 5 and 6 at Buckland are crushed impressions, and poorly preserved, and thus the first observed occurrence of *Anahoplites intermedius* is taken as the line of demarcation between the *dentatus-spathi* and *intermedius* Subzones.

The equivalent of Division 3 of the Greatness section, at Dunton Green, is still exposed, and is similar to the sequence at Greatness. Unfortunately, the upper beds of the Lower Gault, the equivalents of Divisions 4, 5 and 6, are not now exposed at Dunton Green. However, from the description given by Wright (1947) there also appears to be a marked attenuation of the equivalents of Divisions 4 and 5, but the record of *Mojsisovicsia subdelaruei* from five inches beneath the *lautus* Zone nodule bed (Khan, 1952, 73) seems questionable. Wright drew attention to the occurrence, an inch or two beneath the *lautus* Zone nodule bed, of several species of *Dimorphoplites*, and discussed the possibility of their indicating the base of the *lautus-nitidus* Subzone. From the occurrence of ammonites of undoubted *lautus-nitidus* age at Greatness some three to four inches beneath the *lautus* Zone nodule bed, the placing of the similar horizon at Dunton Green in this subzone appears to be confirmed.

4. CONCLUSIONS ON THE ZONING OF THE LOWER GAULT

The Lower Gault includes the Middle Albian zones of *Hoplites dentatus* and *Euhoplites lautus*.

(i) *dentatus* Zone. Spath included in the *dentatus* Zone, in ascending order, the subzones of *Hoplites benettianus*, *Hoplites dentatus* and *H. spathi*, *Anahoplites intermedius* and *Dimorphoplites niobe*. The subzone of '*Diploceras*' *subdelaruei* was classified by Spath with the *lautus* Zone; however, the author follows Khan (1952, 73) in including this subzone in the *dentatus* Zone.

Breistroffer (1947, 68) has named the *dentatus* Zone the 'Zone à *Hoplites dentatus* et *Anahoplites mimeticus*'. *Anahoplites mimeticus* Spath is a rare and incompletely known ammonite of the *benettianus* Subzone (Spath, 1925, 131, pl. XI, fig. 7) in England and does not possess a great stratigraphical range. It is not a characteristic species of the English *dentatus* Zone, and this alteration to the zonal nomenclature is not supported here. It should be noted that the stratigraphical positions of a number of Lower Gault species stated by Breistroffer do not agree with the English occurrences.

Deposits of *benettianus* Subzone age occur in the northern Weald (Wright & Wright, 1948), but the subzone is not represented at Folkestone. The *dentatus-spathi* Subzone is now known to cover a greater time-interval than has been previously thought. At Folkestone, the *dentatus* nodule bed in Bed I is earlier in age than the principal bed of phosphatic nodules representing the *dentatus-spathi* Subzone which occurs in the northern Weald. However, the *dentatus* nodule bed at Folkestone is itself a condensed deposit in which specimens of *Hoplites* occur which are transitional to those found in the *benettianus* Subzone.

Wright (1947, 315) and Casey (1954, 265) considered that the upper *dentatus-spathi* nodule bed ('Bed 1 nodules') at Dunton Green included ammonites of the *intermedius* Subzone as well as species of the *dentatus-spathi* Subzone. Milbourne (1956, 239) included the same horizon at Greatness in the *dentatus-spathi* Subzone whilst he classified the immediately overlying clays with the *intermedius* Subzone, as Casey and Wright had done with the equivalent horizon at Greatness. However, both at Dunton Green, Greatness, Buckland and elsewhere in the Weald, there is a thickness of clay above the upper *dentatus-spathi* nodule bed, and its lateral equivalents, which still contains species of *Hoplites*, such as *H. escragnollensis* Spath. Neither *Anahoplites intermedius* nor *A. praecox* occur in the upper *dentatus-spathi* nodule bed or in the overlying clays which are known to contain *H. escragnollensis* Spath, but appear at a higher level. It is recommended, therefore, that deposits containing *Hoplites escragnollensis* be included in the *dentatus-spathi* Subzone and not, as hitherto, in the *intermedius* Subzone.

The ammonite fauna of the upper part of the *dentatus-spathi* Subzone is characterised by species of *Hoplites*, such as *H. canavarii* Parona & Bonarelli, *H. latesulcatus* Spath, and *H. escragnollensis* Spath, whilst varieties of *H. dentatus* and the later mutation of the typical form occur frequently. The *intermedius* Subzone is characterised by species of *Anahoplites* such as *A. intermedius*, *A. praecox*, and *A. mantelli* Spath, amongst others. In SE. England, the appearance of *Anahoplites* in numbers coincides with the virtual disappearance of *Hoplites*, and, in fact, the suggested division between the *intermedius* and *dentatus-spathi* Subzones falls at this horizon.

From the excellent material obtained from the upper *dentatus-spathi* nodule bed at Buckland (Bed 4) it can be seen that even in the non-lautiform finely costate species of *Hoplites*, resembling, from the lateral viewpoint, species of *Anahoplites*, the ventral sulcus soon deepens as growth proceeded. In fact, it appears from the material now available that the ventral sulcus of most of the species of *Hoplites* progressively deepened as they evolved during *dentatus-spathi* Subzone times. The evolution of *Anahoplites* of the *intermedius-praecox* group from *Hoplites* of the *dentatus* group might not prove to be so straightforward as was previously thought. Deepening of the ventral sulcus associated with lautiform ribbing produces direct transitions to species of *Euhoplites* occurring in the *intermedius* Subzone. The occurrence of a definite groove associated with marked lautiform ribbing on the inner whorls in a few ammonites from Bed 4 at Buckland and the equivalent horizon elsewhere supports the reference of these to *Euhoplites*. The ammonite fauna from this horizon is closely comparable to that described by Parona & Bonarelli (1896) and Spath (1925, pt. III) from Escragnolles (Alpes Maritimes), France.

Deposits of *intermedius* Subzone age are thicker in the northern Weald than at Folkestone, and appear to expand westwards. The distribution of *Euhoplites pricei* Spath may be of use from the stratigraphical viewpoint. It is known to occur in the upper part of Bed II at Folkestone, and from its occurrence in the upper part of Division 3 at Greatness (Milbourne, 1956, 238) it appears that there is an expansion of the lower part of the *intermedius* subzone in the Sevenoaks area when compared to the Folkestone section. There is, however, a slight attenuation of deposits belonging to the restricted *niobe* Subzone at Greatness.

Although Breistroffer (1947, 70) regards the *niobe* Subzone as an horizon of local interest in the English Lower Gault, it marks in Kent a definite interval between the *intermedius* and *subdelaruei* Subzones. The author favours its retention as a distinct subzone notwithstanding the long range of *D. niobe*.

The *subdelaruei* Subzone was originally taken by Spath to include at Folkestone both nodule beds of Bed IV, and was classified with the *lautus* Zone (Spath, 1941, 668). Khan relegated it to the *dentatus* Zone (1952, 73), whilst Milbourne (1956, 241) advised the rejection of a separate subzone of '*Dipoloceras* (*Dipoloceroides*)' *subdelaruei* and included the lower part of Bed IV and its lateral equivalents in the *niobe* Subzone, whilst pointing out that the upper line of nodules in Bed IV and its lateral equivalents probably represented a distinct subzone.

It is recommended here that a separate subzone of *Mojsisovicsia subdelaruei* be retained for the equivalents of the lower part of Bed IV at Folkestone which contains species of *Mojsisovicsia* such as *M. subdelaruei* (Spath), *M. remota* (Spath) and *M. spinulosa* (Spath), and which are more fully developed in other areas of the Weald.

The upper nodule bed (iii) of Bed IV, and the basal few inches of Bed V at Folkestone, and their lateral equivalents in the Weald contain a distinct ammonite fauna, including species of *Euhoplites* such as *E. aspasia*, and the late mutations of *E. loricatus* and *E. subtuberculatus*, together with other ammonites conspecific or closely allied to species occurring below this horizon. The typical species of *Euhoplites* of the *lautus* Zone such as *E. lautus*, *E. truncatus*, *E. nitidus*, *E. opalinus*, *E. proboscideus*, with their characteristic clean-cut ventral channel, do not occur at this horizon. This unindexed subzone should not, therefore, be included in the *lautus-nitidus* Subzone (Milbourne, 1956, 241), and the author favours its exclusion from the *lautus* Zone.

The true *Hoplites dentatus* (J. Sowerby) does not extend above the *dentatus-spathi* Subzone. *Euhoplites loricatus*, however, a distinctive ammonite even when crushed in the clays, ranges up from the *intermedius* Subzone to the base of Bed V at Folkestone and its lateral equivalents elsewhere. This ammonite might be of use for zonal purposes.

(ii) *lautus* Zone. The *lautus* Zone includes in ascending order the subzones of *Euhoplites lautus* and *E. nitidus*, *Anahoplites daviesi*, and *Dipoloceras cristatum*, and forms the uppermost zone of the Middle Albian. Breistroffer (1947, 45, 68, 70) has named the *lautus* Zone the 'Zone à *Hoplites* (*Euhoplites*) *nitidus* et *Dipoloceras* (*Dipoloceroides*) *subdelaruei*', excluding the *cristatum* Subzone, which he included in the Upper Albian. *Euhoplites lautus* occurs typically in Beds V to VII at Folkestone where the strict *lautus* Zone is more fully developed, and, as Spath pointed out, only transitional forms of this species occur in Bed VIII (1928, 265). Even if the *cristatum* Subzone should eventually be included in the Upper Albian, there is no need to rename the *lautus* Zone. *Mojsisovicsia subdelaruei* has already been shown to occupy an horizon beneath the strict *lautus* Zone and is separated from it by a thickness of sediment which does not contain *M. subdelaruei*. It is pertinent to mention here that there is no certain evidence that *M. evansi* (Spath) is of *subdelaruei* Subzone age (Breistroffer, 1947, 45).

At Folkestone, the subzones included in the *lautus* Zone can be differentiated and are represented within Beds V to VIII of the Lower Gault, with a total thickness of about ten feet (Price, 1879, 16–19). When deposits of the *lautus-nitidus*, *daviesi* and *cristatum* Subzones are traced around the northern Weald, they become attenuated. In the Trottiscliffe–Sevenoaks area, they have been shown to be represented principally by a bed of phosphatic nodules and a few inches of clay. In the Reigate area of Surrey, the '*lautus* Zone nodule bed' is absent and as yet no ammonites of *lautus* Zone age have been recorded (Gossling, 1929, 251). Deposits of *lautus-nitidus* Subzone age are now known to occur below the *lautus* Zone nodule bed in the Sevenoaks–Trottiscliffe area.

Breistroffer (1947, 45) has combined the *lautus-nitidus* and *daviesi* Subzones, whilst on page 68 he refers to a 'Sous-zone à *Hoplites* (*Euhoplites*) *nitidus* et *Dipoloceras* (*Dipoloceroides*) *equicostatum*', referring to the *daviesi* Subzone as an 'Horizon à *Anahoplites* *Daviesi*'. Although *Euhoplites lautus* and *E. nitidus* occur in Bed VII, having ranged upwards from Bed V, the occurrence of *Anahoplites daviesi* and varieties marks a definite subzone which contains these species which foreshadow, and in the uppermost part are transitional to, *Epihoplites*. Breistroffer records as characteristic fossils the ammonites '*Dipoloceras* (*Dipoloceroides*) *equicostatum*' Spath, *Engonoceras iris* Spath, and *Proturrilitoides densicostatus* (Passendorfer). In England, these three species are rare, whilst *Engonoceras iris* Spath is still only represented by the holotype.

The *cristatum* Subzone has been included by Breistroffer (1947, 48) in the Upper Albian, but the ammonite fauna of this subzone contains many species closely related or conspecific with ammonites occurring in the *daviesi* and *lautus-nitidus* Subzones below. Although the subzone marks the

introduction in England of a number of genera which attain their maximum development in, and are characteristic of, the Upper Albian, *Mortonicer* and *Hystero* are comparatively rare at this level. There is a thickness of clays above Bed VIII at Folkestone which contains a similar fauna to that occurring in the upper nodule bed of Bed VIII, but *Hystero* only becomes abundant above these clays. In a similar manner, there is a thickness of clays above the *lautus* Zone nodule bed in northern Kent in which *Hystero* is uncommon, and it is only above these clays, the correlatives of the basal part of Bed IX, that *Hystero* becomes abundant. Undoubtedly, the ammonite fauna of the *cristatum* Subzone is a transitional one but a false impression may be gained if it is forgotten that no attempt has yet been made to separate and list the ammonite faunas contained in the lower and upper nodule beds of Bed VIII at Folkestone (Spath, 1942, 674-81). More collecting remains to be done at Folkestone before any definite proposal can be made to alter the zonal classification of the *cristatum* Subzone, but it is unlikely that the lower nodule bed of Bed VIII and its lateral equivalents could be placed in the Upper Albian.

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REFERENCES

- BREISTROFFER, M. 1947. Sur les zones d'Ammonites dans l'Albien de France et d'Angleterre. *Trav. Lab. Géol. Univ. Grenoble*, **26**, 17-104.
- CASEY, R. 1950. The Junction of the Gault and Lower Greensand in East Sussex and at Folkestone, Kent. *Proc. Geol. Ass., Lond.*, **61**, 268-97.
- . 1954. *Falciferella*, a new genus of Gault Ammonites, with a review of the family Aconeceratidae in the British Cretaceous. *Proc. Geol. Ass., Lond.*, **65**, 262-77.
- . 1957. The Cretaceous ammonite genus *Leymeriella* with a systematic account of its British occurrences. *Palaeontology*, **1**, 29-59.
- DE RANCE, C. E. 1868. On the Albian or Gault of Folkestone. *Geol. Mag.*, **5**, 163-71.
- DINES, H. G. & F. H. EDMUNDS. 1933. The Geology of the Country around Reigate and Dorking. *Mem. geol. Surv. U.K.*, 286 (N.S.).
- GOSSLING, F. 1929. The Geology of the Country around Reigate. *Proc. Geol. Ass., Lond.*, **40**, 197-259.
- JUKES-BROWNE, A. J. 1900. The Cretaceous Rocks of Britain. 1, Gault and Upper Greensand of England. *Mem. geol. Surv. U.K.*
- KHAN, M. H. 1952. Zonal analysis of the Lower Gault of Kent based on Foraminifera. *Contr. Cushman. Fdn.*, **3** (2), 71-80.

- KIRKALDY, J. F. 1947. Report of the Field Meeting at Reigate. *Proc. Geol. Ass., Lond.*, **58**, 192-3.
- MILBOURNE, R. A. 1956. The Gault at Greatness Lane, Sevenoaks, Kent. *Proc. Geol. Ass., Lond.*, **66**, 235-42.
- PARONA, C. F. & G. BONARELLI. 1896. Fossili Albiani d'Escagnolles del Nizzardo e della Liguria Occidentale. *Palaeontogr. ital.*, **2**, 53-112, 5 plates.
- PRICE, F. G. H. 1879. *The Gault*. London.
- SPATH, L. F. 1923-43. A Monograph of the Ammonoidea of the Gault. *Palaeontogr. Soc. [Monogr.]*.
- . 1923b. Excursion to Folkestone. With notes on the zones of the Gault. *Proc. Geol. Ass., Lond.*, **34**, 70-6.
- . 1925b. Notes on the Ammonites of the Lower Greensand and Gault. Folkestone and Neighbourhood. In Walton, J. W. *Folkestone and the Country Around*, 31-6.
- . 1926b. On the Zones of the Cenomanian and the uppermost Albian. *Proc. Geol. Ass., Lond.*, **37**, 420-32.
- . 1935b. Field meeting at Folkestone, Kent. *Proc. Geol. Ass., Lond.*, **46**, 429-31.
- WRIGHT, C. W. in WRIGHT, C.W. & H. D. THOMAS. 1947. Notes on the Geology of the Country around Sevenoaks, Kent. 1, The Gault of Dunton Green. *Proc. Geol. Ass., Lond.*, **57**, 315-18.
- & E. V. WRIGHT. 1948. Note on two exposures of the base of the Gault in Surrey. *Proc. Geol. Ass., Lond.*, **59**, 84-6.

The Petrology of the Carboniferous Rocks near Stranraer, Wigtownshire

by J. G. C. M. FULLER

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ABSTRACT: Millstone Grit sandstones, siltstones and clays near Stranraer contain plant remains, totally oxidised sphaerosiderite, and vug-filling 'chlorite'. Notable heavy detrital minerals include monazite, not from local sources, and picotite-chromite originally from the Ballantrae Igneous Series. The deposits fringed the Ayrshire basalt and coal-forming province. They were reddened before accumulation of the local New Red Sandstone, to which they bequeathed material.

1. INTRODUCTION

PARALLEL with the western side of Loch Ryan, on the Galloway coast, sandstones and shales presumed to be of Millstone Grit age lie sandwiched between the upturned edges of Ordovician greywackes and a thick cover of New Red Sandstone conglomerates (Fig. 1). The Carboniferous rocks are soft and weakly resistant to weathering; the ground is low-lying, and exposures (Appendix 1) are infrequent, but it is reasonably certain that the outcrop exists through an eight-mile long strip between Sloughnagarry (034706)¹ and Low Knockglass (048586), and is at the most about 100 feet thick. Formation contacts are obscured and the lithological sequence is uncertain, though argillaceous rocks dominate the lower part and arenaceous rocks the upper part.

These Carboniferous beds formed part of the floor upon which accumulated the sands and gravels of the New Red Sandstone; their wastage

¹ The six-figure grid references all lie in the 100 km. square 25 (NX).

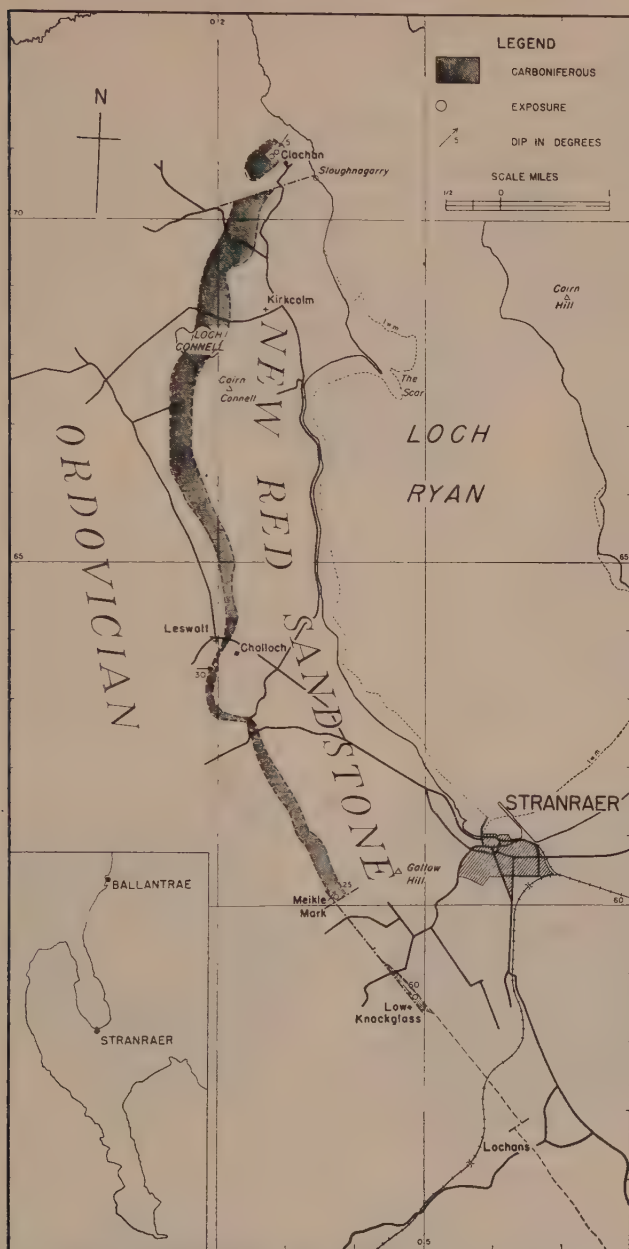


Fig. 1. Geological sketch-map of the Carboniferous outcrop near Stranraer

added substantially to the New Red Sandstone, and with this in mind they are here described.

2. RETROSPECT

J. C. Moore, as early as 1842, reported that these beds of red and white sandstones, clays and micaceous shales had 'long been known to exist' and had led to 'several fruitless searches for coal'. Their Carboniferous age was confirmed from poorly preserved fossil plants (including *Alethopteris lonchitica*) by the Geological Survey (Geikie & Irvine, 1873), and correlated as probably Upper Carboniferous (Peach, 1897). New surveys in search of refractories revealed a thin olivine-basalt lava low in the sequence (Geological Survey, 1918; Howe, 1920, 1923; Wilson, 1922).

3. PETROLOGY

(a) Sandstones

Abundantly micaceous, evenly bedded, well-sorted, crimson, purple and yellow soft sandstones typify the upper beds. Most quartz grains display glistening euhedral overgrowths optically continuous with their cores; in some, imprisoned iron-oxide specks outline detrital shapes which range from sub-angular to angular. Iron-oxide powder fills pore-spaces in coloured beds, and reached 10% by weight of some purple samples (Challoch, 022637). Feldspars—orthoclase, microcline, and albite-oligoclase—make up about one tenth of the sand grains; other minerals are described below.

(b) Fireclays

Refractory clays approximating to kaolin in composition (Geological Survey, 1924, 47) have been known to exist near Stranraer since the Survey revision of 1897 (Peach); they occur notably at Meikle Mark (037601) and Low Knockglass (048587). The fireclays contain disseminated iron oxide, clastic quartz, some feldspar, and a suite of minute heavy mineral grains similar to those of the associated sandstones.

(c) Ironstones

Feldspar-free silty clays of the lower part of the succession contain abundant (about 250 per cubic centimetre) bright-crimson spherical iron-oxide bodies thought to be altered siderite spherulites (Plate 2 A). They range in size from half to one millimetre diameter, and are occasionally oval, bilobate or trilobate. Surface textures of the spheres vary with the grade of host rock, from smooth in clays to very irregular in coarse siltstones. Internally, the majority comprise two or three concentric shells;

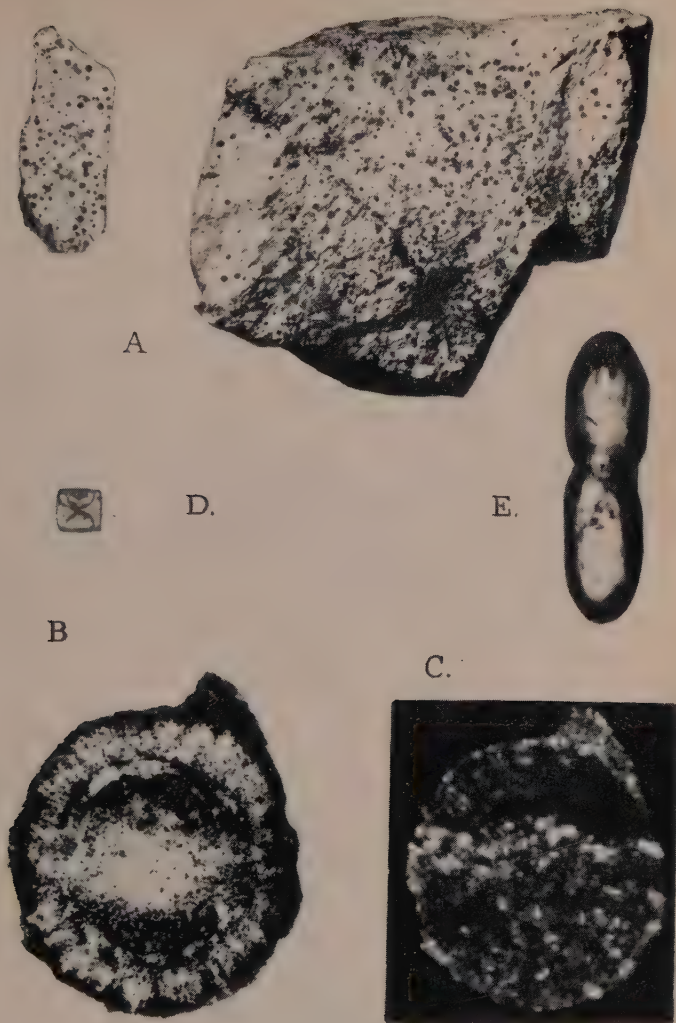


Plate A. Silty clay spotted with iron-oxide pseudomorphs of spherulitic siderite, Meikle Mark (037601). $\times 0.9$.

B. Thin section, ordinary light, of a spherulitic iron-oxide pseudomorph after acid treatment. Note concentric and radial structure. $\times 39$.

C. As B, crossed nicols. Note bedding of detrital material.

D. Authigenic brookite crystal, ordinary light, showing sigmoidal lines which separate optically dispersed and non-dispersed areas. Dispersed portions at left and right; optic axial plane for red light horizontal. $\times 150$.

E. Zircon; an unusual 'capped' crystal. $\times 150$.

in some, a close-packed radiating-fibre pattern in the iron oxide is discernible. Thin sections (Plate 2B) bleached by Spencer's (1925) method reveal a distinct radial orientation of clay wisps, some of which by optical methods is identifiable as kaolinite. Tangentially oriented shreds of clay are concentrated at the peripheries and at shell boundaries.

On the other hand, grains of detrital quartz within the spheres retain the bedding alignment and grace of the host rock (Plate 2C). Evidently, the iron-oxide bodies pseudomorphed a post-depositional spherulitic mineral, which both structurally and environmentally resembled sphaerosiderite. In habit, size, structure and mineral association they match the sphaerosiderites in the Millstone Grit and Coal Measures of west Yorkshire (Deans, 1934).

At one locality (Meikle Mark, 037601) aggregates of a pale-green, easily oxidised chlorite-like silicate filled small fissures and irregular vugs (up to 1 mm. width) in the ironstones (cf. Deans, 1934). Optically, it is cloudy, weakly pleochroic (X = pale olive- or bluish-green, Y or Z = darker), weakly birefringent, negative, with variable 2V (20° to 30°) and refractive index ranging from 1.57(7) to 1.58(2). The mineral may be a bleached chamosite. Why it escaped complete oxidation along with the sphaerosiderite is obscure; possibly it post-dated the time of oxidation, or at least part of it, and was a secondary product from an interaction of ferrous solutions and clay minerals (cf. Taylor, 1949, 89).

(d) Heavy Minerals

Of particular interest in the heavy residues (Tables I and II; Appendix 2) are the relatively large amounts of monazite and picotite-chromite spinel. Among its possible sources, monazite is probably absent both from the Ordovician country rocks of the Stranraer-Ballantrae area, and from the nearest Old Red Sandstone, about twenty-two miles north of Stranraer (Mackie, 1929; author's unpublished work) and is very rare in the Gallo-way granites (Teall, 1899, 620). It has been reported as relatively abundant (Boswell, 1928, 138) in the Carboniferous sandstones of the Midland Valley of Scotland, but there, wholly unlike the Stranraer occurrence, it was accompanied by staurolite, garnet and, rarely, kyanite. At present its source is unknown.

Picotite-chromite spinel, on the other hand, is plentiful in the local Ordovician sediments, and doubtless originated in the serpentines of the Arenig igneous series at Ballantrae (author's unpublished work). It is apparently less frequent in coarser grades of the Stranraer Carboniferous (Table II), whereas monazite is more frequent: their frequencies depend on particle-size, and by this may reflect the original source-rock differences.

The remaining heavy detrital minerals of the Stranraer Carboniferous—

apatite, anatase (some), iron ores, rutile, tourmaline and zircon—are optically similar to those in the surrounding Ordovician greywackes. Authigenic minerals—anatase, brookite and 'leucoxene'—are described in Appendix 2.

TABLE I

Heavy Detrital Minerals Mean % Composition ¹	
Zircon	64.4
Pink	4.0
Colourless (anhedral)	84.3
Colourless (euhedral) ²	3.8
Zoned	3.7
Cloudy	4.3
Tourmaline	13.4
Blue, bluish-green	14.9
Green	36.5
Olive	37.6
Brown	11.1
Colour-zoned	(4.2)
Rutile	15.5
Yellow-red	96.3
Greenish-brown	3.7
Picotite-chromite spinel	3.6
Monazite	3.1
Anatase ³	(4.4)
Apatite	(0 to 27)
Brookite ³	(0.4)
Black iron ores	(not counted; rare)
'Leucoxene'	(not counted; abundant)

¹ 6 subsamples totalling 3034 grains (excluding anatase, apatite, iron ores and 'leucoxene').

² Terminal faces preserved.

³ Excluding micro-aggregates.

(e) Basalt

Decomposed vesicular basalt outcropping among Carboniferous sediments in the bay of Sloughnagarry (034706) comprises a more or less aligned felt of altered twinned feldspar laths (? labradorite), the majority about 0.5 mm. by 0.05 mm. in size, with chlorite, iron oxide and calcite filling the interstices. Some chlorite patches containing shreds of iron oxide disposed at 90-degree angles probably replaces pyroxene. Sporadic, completely altered, cloudy white insets, measuring up to 0.35 mm. width, may be feldspar. Vesicles range from 0.5 to 1 mm. diameter, and are filled by clusters of radiating chlorite and calcite.

This outcrop may be connected with an olivine-basalt recorded by the Geological Survey (Sheet 3, 1923) about three miles south-west near Loch Connell.

4. DEPOSITION AND LATER EVENTS

Though remains of coal-forming plants and at least one rootlet bed (Meikle Mark) exist in the Stranraer Millstone Grit rocks, depositional conditions seem to have been mainly oxidative, and the plant tissues were destroyed; but a contemporary physical connection between these deposits and the coal-bearing Millstone Grit of Ayrshire is attested by the thin basalt lava interbedded with fireclays, of a kind developed extensively among the lateritised Ayrshire basalts.

On occasion, the water depositing the finer sediment was so richly charged with iron compounds that precipitation occurred. Neither the manner of precipitation nor the way in which the iron was first held in the sediment is known, but a post-sedimentation precipitation or re-precipitation of iron in the form of sphaerosiderite is certain.

Toward the end of Millstone Grit accumulation, or after it, profound weathering completely oxidised the sphaerosiderite. The process may have occurred in stages at any time from Millstone Grit to the opening of New Red Sandstone deposition, but a later time is improbable, for crimson-red fragments of Carboniferous rock are enclosed in the brick-red New Red Sandstone conglomerates. Furthermore, the iron oxide of the New Red Sandstone deposits coats the grains in tough pellicles, whereas that in the Carboniferous, apart from the altered sphaerosiderites, is a pore-filling, pre-silicification, powder. The simultaneous production of these two distinct habits in contiguous arenaceous beds by the same agency seems less likely than their production by different agencies at different times: one by Carboniferous lateritic weathering, and the other by New Red Sandstone erosion of deeply reddened country rocks.

The amount of the Carboniferous bequest to the New Red Sandstone may be greater than that implied by the inclusion in the conglomerate of a few ($< 0.1\%$) fireclay and (? Carboniferous) sandstone pebbles: two detrital minerals, brookite ('standard' type of Rastall, 1938) and monazite, although they numbered less than 1% of the non-opaque heavy residues of the New Red Sandstone conglomerate matrix, are absent both from the greywacke country rocks and the greywacke pebbles of the conglomerate (author's unpublished work). Among their possible sources in the Stranraer region, they have been found only in the Carboniferous.

APPENDIX 1. EXPOSURES

Low Knockglass (048587). Knockglass Burn: purple and yellow sandstones, purple shale and fireclay; dip south-easterly at 60° .

Meikle Mark (037601). Farm track side: silty and sandy iron-spotted clays; rubbly rootlet bed with ramifying limonite- and clay-filled channels a few millimetres in diameter; contorted strata; dip vertical. Burn side: crimson and yellow sandstones, purple shales; dip easterly at 25°.

Challoch (022637). Ditch (019635): purple sandstones and shales with ? *Stigmara* impressions; dip N.100° E at 30°. Probably the site of Moore's (1842) 'quarry at Challock'.

Sloughnagarry (034706). Beach, low tide: green weathered basalt, crimson and grey sandstones and shales; contorted strata; dip vertical.

Clachan (030709). Burn (029711): iron-spotted silty and sandy clays containing flattened, silt-filled, limonite-coated, branching tubes (4 mm. to 8 mm. long diameter) resembling *Stigmara*. Crimson and yellow sandstones above; dip southwesterly at 5°.

APPENDIX 2. HEAVY MINERALS

(specific gravities > 2.9)

(a) Descriptions

These descriptions are based on bromoform separations of ten samples of sandstone and siltstone drawn from the five localities listed in Appendix 1.

(i) **Anatase.** Pale-yellow euhedral authigenic (001) plates, occasionally with narrow dome faces and pyramids, occur as large detached crystals (up to 200 microns wide), often overgrown on a rounded anatase core, or as smaller tablets encrusting 'leucoxene' aggregates. Larger single plates range from 2 to 8% of non-opaque residues. Partly rounded rough-surfaced detrital grains reflect pale blue from incident light.

(ii) **Apatite.** In some sandstones apatite numerically equals zircon, but is absent from others. Water-clear irregularly rounded to prismatic grains formed the bulk.

(iii) **Brookite.** Three distinct varieties occur: (i) pale-yellow, unworn, authigenic, striated (100) plates, yielding optical interference figures of Rastall's (1938) 'standard' type (not found with other varieties); (ii) yellow-brown, cloudy, non-dispersed plates (Phillips, 1932), tabular parallel to (001), usually measuring about 30 by 70 microns, with rough surfaces (found at Challock); and (iii) yellow or orange tabular crystals (also found at Challock), the largest measuring 30 by 50 microns, mostly forming 'leucoxene' aggregates, and characterised by crossed sigmoidal lines separating two optically dispersed from two non-dispersed areas (Plate 2 D). The dispersed portions yield central 'standard' interference figures, the optic axial plane for red light bisecting the acute angles between the crossed sigmoidal lines.

(iv) **Iron ores and 'Leucoxene'.** Abundant pale-yellow or white 'leucoxene' aggregates are mostly anatase; black iron-ore occurs uncommonly, often as 'leucoxene' cores. Quantities of red iron-oxide vary greatly.

(v) **Monazite.** Clear, pale-yellow subhedral prismatic to rounded irregular grains, reacting to spectroscopic tests, together with a few highly rounded, pitted, slightly brown-surfaced grains, number as high as 8% of some sandstone residues (Clachan).

(vi) **Rutile.** Fresh angular anhedral to prismatic euhedral grains, varying in colour from yellow to deep 'fox-red', and frequently twinned parallel to (101), typified the coarser sandstones. In siltstones it was scarcer and often striated and 'frayed' at prism terminations.

(vii) **Spinel.** Glassy-clear brown to opaque black angular or slightly worn picotite-chromite spinel occurs in all size grades, most commonly in fine sandstones and siltstones.

(viii) **Tourmaline.** The grains are very variable in shape and colour. Colours range from bright blue, through bluish-green, green, olive-green, to brown. Blue varieties are concentrated in coarser grades. Colour-zoned grains (about 4%) unite all classes and closely match those in the surrounding Ordovician greywackes.

(ix) **Zircon.** Colourless worn grains dominate the residues, but euhedral, zoned, cloudy and pink grains are constantly present. An unusual 'capped' crystal like that figured by Thomas (1902, pl. XXXI, fig. 3) is illustrated in Plate 2 E.

(b) Quantitative Data

TABLE II

Locality	Lithology	Z.S.I. ¹	Heavy Detrital Composition % ²					No. of Grains
			<i>Z</i>	<i>T</i>	<i>R</i>	<i>Sp</i>	<i>Mon</i>	
Clachan 030709	pale-yellow sandstone	71	53.3	14.1	23.5	1.7	7.5	533
Meikle Mark 037601	white sandstone	55	68.4	14.3	12.9	1.7	2.7	412
Challoch 019635	purple sandstone	50	62.1	8.8	19.7	4.1	5.3	543
Sloughnagarra 034706	dark vari-coloured sandstone	50	64.5	18.1	13.3	1.7	2.4	541
Low Knockglass 048587	dark purple fine sandstone	41	65.2	17.1	10.8	6.3	0.6	474
Meikle Mark 037601	purple sandy fireclay	38	73.1	8.1	13.0	5.8	(<0.2) ³	531

¹ Zircon size index, mean of intermediate diameters, 50-grain subsamples.

² Exclusive of anatase, apatite, iron ores and 'leucoxene'.

³ Not counted; rare surface-altered grains included as zircon.

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REFERENCES

- BOSWELL, P. G. H. 1928. The rarer detrital minerals of British sedimentary rocks. *Trans. geol. Soc. Glasg.*, **18** (1), 129-48.
- DEANS, T. 1934. The spherulitic ironstones of west Yorkshire. *Geol. Mag.*, **71**, 49-65.
- GEOLOGICAL SURVEY. GEIKIE, A. & D. R. IRVINE. 1873. Explanation of Sheet 3 (Scotland) in the One Inch Series. *Mem. geol. Surv. U.K.*
- . 1918. *Summ. Progr. geol. Surv., Lond.* (for 1917).
- . J. A. HOWE (Ed.). 1920. Refractory materials: fireclays. *Spec. Rep. Min. Resour. G.B.*, **14**.
- . ENNOS, F. R. & A. SCOTT. 1924. Refractory materials: fireclays. *Spec. Rep. Min. Resour. G.B.*, **28**.
- MACKIE, W. 1929. Preliminary report of the heavy minerals of the Silurian rocks of south Scotland. *Rep. Brit. Ass.* (Glasgow, 1928), 556.
- MOORE, J. C. 1842. On the rocks which form the west shore of the bay of Loch Ryan in Wigtownshire. *Proc. geol. Soc. Lond.*, **3**, 277-8.
- PEACH, B. N. 1897. In Geikie, A., 1897, Annual Report of the Geological Survey of the United Kingdom for 1896. *44th Report Dept. Art and Science*, Appendix E.
- PHILLIPS, F. C. 1932. Crystals of brookite tabular parallel to the basal plane. *Miner. Mag.*, **23**, 126-9.
- RASTALL, R. H. 1938. On brookite crystals in the Dogger. *Geol. Mag.*, **75**, 433-40.
- SPENCER, E. 1925. Occurrences of spherulitic siderite and other carbonates in sediments. *Quart. J. geol. Soc. Lond.*, **81**, 667-705.
- TAYLOR, J. H. 1949. Petrology of the Northampton Sand Ironstone Formation. *Mem. geol. Surv. U.K.*
- TEALL, J. J. H. 1899. The Silurian rocks of Britain. Vol. 1, Scotland. *Mem. geol. Surv. U.K.*
- THOMAS, H. H. 1902. The mineralogical constitution of the finer materials of the Bunter Pebble Bed in the west of England. *Quart. J. geol. Soc. Lond.*, **58**, 620-32.
- WILSON, G. V. 1922. The Ayrshire bauxitic clay. *Mem. geol. Surv. U.K.*

Field Meeting at Reigate

*An introductory meeting for those who had done little or no geology
in the field*

18 September 1957

Report by the Director: J. M. HANCOCK

Received 5 June 1958

THE TRAVERSE followed at this meeting is suitable for the beginner who wishes to see some common sediments and collect fossils in various states of preservation. The total walking distance is about four miles. To enter the sand-pit at Buckland, written permission should be obtained from the Buckland Sand & Silica Co. well in advance of the visit.

Some twenty-five members and friends met outside Reigate station at 2.15 p.m. Turning right on leaving the station yard, the party walked northwards to the foot of Reigate Hill where the main road bends eastwards. Following the footpath immediately east of the last house on the north side of the bend, the hill was ascended with the clump of pine trees and old chalk-pit on the left. Near the top of the hill and just above the chalk-pit, the party reassembled to examine the expression of the geology as seen in the topography viewed to the south (51/256519).

The foot of the hill marks the base of the Chalk, the gentle incline towards the foot of the hill is on Upper Greensand, whilst the strip of level ground beyond this and north of the railway is underlain by Gault clay; Reigate itself is built on dumpy hills of Lower Greensand. All these formations dip north at a low angle forming the northern limb of the Wealden anticlinorium. The more distant view is usually visible with the broad expanse of flat Weald Clay country backed by another range of gentle hills—the forested land of the central Weald formed by Hastings Sands. On a clear day the South Downs on the southern limb of the anticlinorium can be seen.

The party entered the chalk-pit from the east side by a rough path amongst the pines. In this part of the quarry there is a clean section showing several feet of Plenus Marls overlain by the pebbly Melbourn Rock. The bedding is revealed by the marl bands and from these it can be seen that the dip is very low and that there is some minor faulting. The commonest fossil in the Plenus Marls is *Ostrea vesicularis* Lamarck but members also found *Orbirhynchia* and an *Actinocamax* whose slender guard shows it to be *A. primus* Arkhangelsky. In the Melbourn Rock *Inoceramus labiatus* (Schlotheim) is the only common fossil but casts of *Sciponoceras* can also be found.

Climbing out of the pit and returning to the road, the party followed the lane eastwards running along the foot of the escarpment. At the foot of Colley Hill (51/244520) are two pits on either side of the turning off the path to the south. The one on the east of the turning is long disused, but by following the old track amongst the trees can be found a slope in which Chalk Marl and Glauconitic Marl at the base of the Chalk can be exposed by digging with a mattock. The Glauconitic Marl contains dark phosphatic nodules but most of the fossils are preserved either as casts in the sandy marl or with their original shells. Lamellibranchs are the most frequent fossils (particularly *Syncyclonema* and *Neithea*) but the diligent collecting of members produced examples of many groups. The ammonites include *Schloenbachia* spp., *Mantelliceras* and *Hypoturrillites*—a typical Lower Cenomanian assemblage.

The pit on the west of the path shows some fifteen feet of Coombe Rock, an irregularly bedded periglacial sludge. There is an adit leading into the hillside for the mining of hearthstone from the Upper Greensand. Members were only able to examine this rock from loose blocks.

Here it was necessary to turn back on to the path at the foot of the Chalk scarp and continue eastwards nearly to Juniper Hill (51/239520), where a sharp southward turn was taken. This track leads across Upper Greensand and Gault and the Director pointed out that to map the boundary between these two formations an auger would often be useful.

Just south of the railway bridge the party cut across the field on the right and entered the north-eastern corner of the Buckland sand-pit (51/237511). This provides an extensive exposure of Gault resting on the Folkestone Beds of the Lower Greensand. Mr. H. G. Owen, who has been making a study of the Gault here, informs the Director that the bottom seven feet, with numerous gritty phosphatic nodules but very few fossils, belong to the *Douvilleiceras mammilatum* Zone. From the Zone of *Hoplites dentatus* above members obtained a number of examples of *Hoplites* spp. and noted also the numerous needles of gypsum dispersed through the clay.

Moving down to the floor of the sand-pit, the Folkestone Sands were examined. The Director pointed out that both true and false bedding were developed, and that walls of the pit were so cut as to show the appearance of both strike and dip sections of the false current bedding. This showed the direction of the depositional currents to be from the north. Members were invited to consider how the bedding was expressed in the sands, the degree of sorting, the mineral composition, the roundness and sphericity of the grains and the quality of the surface texture.

Before leaving the pit, Mr. J. Kaser voiced the appreciation of the party. Members then returned to Reigate on foot or by bus from the main road at Shegbrook.

Field Meeting at the Palisadoes, Jamaica

JAMAICA GROUP

26 May 1957

Director: V. A. ZANS

Report by L. J. CHUBB

THIRTY-FIVE MEMBERS and friends assembled at the meeting place in Kingston and drove to Harbour Head at the eastern end of Kingston Harbour.

From this point the Palisadoes, a long sand-bar, extends in a westerly direction for a distance of about nine miles, forming the southern side of Kingston Harbour. At its narrowest point it is little more than sixty yards wide though it usually attains a breadth of 150 to 250 yards. Nearly halfway along its length it widens to about a mile, to form Kingston Airport, and at its western end expands again and carries the old town of Port Royal.

The origin of the Palisadoes was discussed. From the outer beach the strong westerly drift was observed. The waves, driven by the prevailing south-easterly wind, carry sand and shingle obliquely up the beach, but the water, sand and pebbles recede under the influence of gravity straight down the slope. The result is a zig-zag movement towards the west. The Caribbean Current too, a branch of the Atlantic North Equatorial Current, reinforced by water from the South Equatorial Current, strengthens the drift from east to west.

Old maps show the areas of the airport and Port Royal as separate islands or cays, resembling those still seen a mile or two to the south. The delta of the Hope River lies immediately east of Harbour Head and it is evident that the Palisadoes started as a sandspit, which grew westwards from this delta, the material being brought down by the Hope and other rivers from the interior of the Blue Mountains. The spit extended westwards until it reached the Airport Cay, and thence four miles farther to the Port Royal Cay, forming a complex *tombolo*.

The beaches on both sides were visited, and the marine organisms characteristic of the sheltered lagoonal environment on the harbour side, were compared with those of the wave-battered banks and reefs of the open sea.

At the Soil Mechanics Laboratory, operated by John Mowlem & Company Limited, the party was welcomed by Mr. J. L. Bray. He explained the difficulties encountered in lengthening the principal runway of

the Airport which was being extended over the shallow offshore water of the harbour. Afterwards the party was divided into three groups, under the leadership respectively of Mr. Bray, Mr. W. A. B. Guest, soil scientist, and Mr. J. Haynes, engineer, and were given a demonstration of the techniques employed in the study of soil mechanics. Lunch was taken on the verandah of the Company's office.

The party then proceeded to Port Royal, the old capital of the island, which was destroyed by a devastating earthquake on 7 June 1692. According to contemporary observers there were three shocks, which shook down and drowned nine-tenths of the town in two minutes, the houses sinking into thirty feet of water. From the coastguard's watch-tower the party surveyed the submerged area, which extends over many acres. It is uncertain whether the subsidence was the direct effect of faulting or whether it was due to a landslide brought about by the earthquake. A recent borehole showed that, beneath the superficial sand and gravel, a fine running sand or quicksand occurs at thirty-one to fifty-two feet; the deeper parts of the hole, to a depth of 336 feet, were in coralline limestone, which may represent the Miocene August Town Formation. Probably the layer of quicksand rendered the ground unstable, and aided by the overloading of the surface with wharfs, warehouses, homes, taverns, etc., the earthquake precipitated a landslide. A visit was paid to the tomb of Lewis Galdy who according to his epitaph 'was swallowed up in the great earthquake of 1692 and by the providence of God was by another shock thrown into the sea. . . .'

The earthquake of 14 January 1907, which destroyed Kingston, also seriously damaged Port Royal. In this connection a visit was paid to the 'Giddy House', a small brick building which was tilted to an angle of about 15°. Again there is some uncertainty as to whether the movement was directly due to faulting or whether to a shifting of the sand on which it is built. Near and parallel to the sunken side of the house there is a long, straight depression in the sand, on the farther side of which a large concrete gun-emplacement is similarly tilted. Possibly the depression is a surface manifestation of a fault in the underlying August Town Limestone.

The party returned to Kingston at about 6 p.m.

REFERENCES

- SLOANE, HANS, *et al.* 1693. A letter from Hans Sloane, M.D. and S.R.S., with several Accounts of the Earthquakes in Peru, Oct. 20, 1687; and at Jamaica, Feb. 19, 1687-8; and June 7, 1692. *Phil. Trans. Roy. Soc.*, **18**, 78.
- STEERS, J. A. 1940. The Cays and the Palisadoes, Port Royal, Jamaica. *Geogr. Rev.*, **30**, 279-96.

Field Meeting to Study the Gypsum Deposits of Eastern St. Andrew, Jamaica

JAMAICA GROUP

28 July 1957

Directors: V. A. ZANS and R. P. CONNETT

Report by V. A. ZANS

THE PARTY, comprising twenty members and friends, drove from Kingston to the main office of Jamaica Gypsum Ltd. at Harbour Head. Here they were welcomed by Mr. R. P. Connett, Managing Director of the Company, who gave a talk on gypsum, its composition and occurrence, its uses, and the methods employed in quarrying and processing it.

The party drove eastwards to the Company's quarries at Brooks, near Bull Bay, where members were conducted through the workings by Mr. Connett and his assistants, Messrs. Donald Dunn and Michael C. Lewes. The route passed the old quarry, where operations were first started in 1949, and ascended steeply through Halberstadt Limestone to the crushing plant and the new quarry in the Brooks West deposit, at about 1000 feet above sea-level. The gypsum is won by blasting and by mechanical excavators in benches each about twenty-five feet high. The mining faces provide excellent exposures of the deposit, which is of high quality averaging well over 90% of pure gypsum. The present rate of production is about 1000–1200 tons per day.

The occurrence of gypsum in this area was reported by Sawkins (1869) and Matley (1946), but its extent and potential economic value were not realised until several years later. In 1949–51 the deposits were mapped by the Geological Survey (Zans, 1951), and in 1954 over thirty exploratory boreholes were drilled in them by the Department and by the companies interested. These proved that the larger gypsum bodies contained cores of anhydrite, a mineral unknown in Jamaica at the surface; it was calculated that the largest deposit (Brooks West) consisted of an upper gypsum layer of 5.5 million tons, underlain by an anhydrite lens of some 2.7 million tons, below which there was another 2 million tons of gypsum. Other deposits on the property contained about 6 million tons of gypsum (Zans, 1955).

Several other gypsum bodies occur in two roughly parallel zones near the margins of the Port Royal Mountains, a much folded belt of Eocene

rocks lying between the Wagwater and Yallahs thrusts. The largest deposits are associated with the purple beds at the base of the early Eocene Wagwater series but lenses of gypsum occur also in the Lower and Middle Eocene shales. The form of the gypsum bodies and their relationship to the country rock suggest that they are diapiric masses, squeezed up from a deeper horizon during the Eocene orogeny. This view is confirmed by the structures, such as schistosity, brecciation, streaking and shearing often shown by the gypsum.

From the quarry the party walked northwards towards Beito, and saw karst phenomena due to the solution of the gypsum by rainwater, including enlarged joints, small sinkholes, fretted surfaces and even a cave, similar to those commonly seen in the limestone areas of Jamaica.

Lunch was taken in the quarry offices, refreshments being provided by the Company. The party then drove eastwards to Eleven Miles, where the Cambridge Hill-Llandewy road was taken. About a mile beyond the road-junction an interesting section was seen, showing the base of the White Limestone Formation and the underlying beds, in a nearly vertical position. According to Matley (1951) the Yellow Limestone facies of the Middle Eocene, commonly seen in the central and western parts of Jamaica, is rarely developed in the eastern part, its place being taken by a brown clay containing disseminated gypsum crystals and pseudomorphs after halite (rock salt), which he called the White Limestone Basement Series. There has been some doubt as to whether this brown clay is in fact the equivalent of the Yellow Limestone but the road section under discussion shows the two facies in close association, the White Limestone being immediately underlain by a few feet of shaly Yellow Limestone, containing the typical fauna of gastropods, echinoids, etc., passing down into the brown clay with pseudomorphs. Beyond this the Carbonaceous Shale or Richmond Beds of Lower Eocene age are well developed.

The next stop was at Cambridge Hill, where a small outcrop of gypsum in the White Limestone Basement Series, carrying disseminated crystals of iron and copper pyrites, was examined. The origin of the sulphide minerals was discussed. Thence the party proceeded to Llandewy and turned south-eastwards, taking the Easington road which runs beside the Yallahs River. Rocks of typical Yellow Limestone facies containing a fauna of echinoids and mollusca were seen. From Easington for a distance of three miles the road is cut into the White Limestone and a stop was made at Easington bridge to examine the well-bedded basal strata of this formation. The main coastal road was reached again at Albion.

On the return journey another stop was made at Grant's Pen, about two miles west of Albion, where the party walked along a disused road cut into the cliff face, and descended thence to the beach. The rocks seen were Eocene clays and shales, in which good arrow-head twin crystals and veins

of fibrous gypsum (satin spar) were found. Small seams of lignite and lignitic clay occur in the same shaly beds.

Returning to Grant's Pen by way of the beach members drove to the fourteenth mile-post, where a fresh road-cutting showed the base of the White Limestone underlain by a few feet of yellowish marl. Beneath this is the brown clay with excellent halite pseudomorphs, varying in size from a quarter inch to one inch or more, many of them showing the characteristic 'hopper' faces. Normally these pseudomorphs have an outer crust of brown impure calcite, and a core of gypsum, consisting of a single crystal which often has the form of a nearly perfect cube. Sometimes the gypsum is visible in the bottom of the hollow faces.

After a full and interesting day the party returned to Kingston in the late afternoon.

REFERENCES

- MATLEY, C. A. 1946. *Outline of the Geology of the Kingston District of Jamaica*. Crown Agents for the Colonies, London.
- . 1951. *Geology and Physiography of the Kingston District, Jamaica*. *ibid*.
- SAWKINS, J. G. 1869. Reports on the Geology of Jamaica. *Mem. geol. Surv. U.K.*
- ZANS, V. A. 1951. Economic Geology and Mineral Resources of Jamaica. *Geol. Surv. Jamaica, Bull. 1*.
- . 1955. Summary Report on the Volume of Gypsum Deposits on the Bellrock Caribbean Property. Appendix B, *Ann. Rept. (1953-4) Geol. Surv. Jamaica*.

Field Meeting at Green Bay and Port Henderson Hill, Jamaica

JAMAICA GROUP

29 September 1957

Report by the Director: L. J. CHUBB

THE PRINCIPAL object of this meeting was to study the highly controversial section exposed in Green Bay at the western end of Kingston Harbour, usually referred to in geological literature as the 'Lazaretto Section', though the Lazaretto buildings have now been demolished.

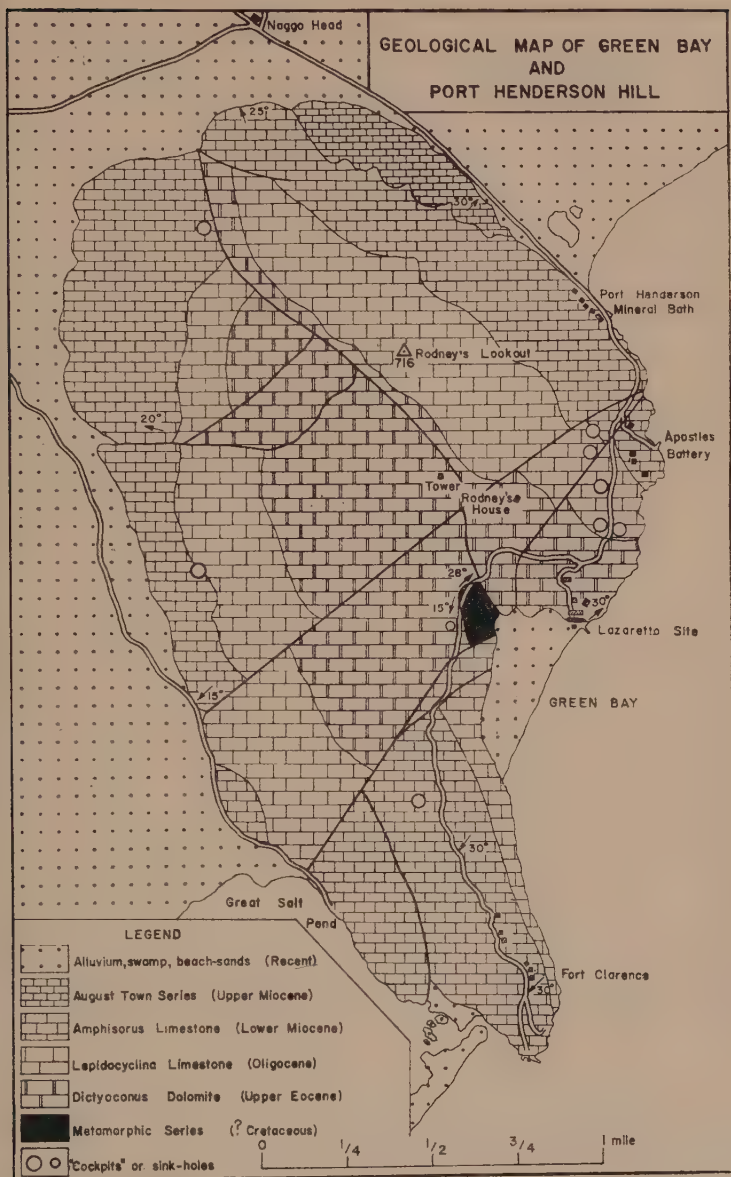
Heavy rain in the early morning was probably responsible for the smallness of the party. Only nine members and friends assembled, and were rewarded with fair weather all day. They drove in three cars westwards to Spanish Town, and thence south-east to Naggo Head. From here to Port Henderson the road skirts the north-eastern flank of the hill.

Port Henderson Hill consists of an anticline composed mainly of the White Limestone Formation, which rises above the alluvium of the St. Catherine Plain to a maximum height of 716 feet at Rodney's Lookout. The axis of the anticline trends NW.-SE. and its eastern part has been removed, partly by faulting and partly by marine erosion, and this side faces the sea in a line of steep cliffs.

On the north-eastern slope of the hill August Town Beds, of Upper Miocene age, overlie the White Limestone, with a dip of 30° NE. The road passes several small quarries in these beds, which consist of impure yellow marls and limestones. From them a number of typical August Town fossils were collected including *Gypsina globulus* (Reuss), *Kuphus* cf. *arenarius* (Linn.) and *Placocyathus* sp. The largest quarry still being worked shows impure rubbly and nodular yellowish limestone without fossils. A small fault was seen here.

The next stop was at Port Henderson, formerly an important place but now ruinous and almost deserted. The derelict 'mineral' bath was inspected. It is fed by a spring issuing from the White Limestone, and probably its salinity is due to contamination by sea-water. Beyond this village the road turns south, narrows and rises over the White Limestone to a height of 250-300 feet, keeping more or less parallel to the coast.

Between Port Henderson and Green Bay, a distance of almost one mile, the road traverses the northern flank of the anticline, passing over the whole succession of the White Limestone Formation in reverse order, the prevailing dip being about 30° NE.



The highest beds, immediately below the August Town Formation, are pure white limestones yielding *Amphisorus matleyi* Vaughan, and are therefore of Lower Miocene age. The buildings and installations of the Apostles Battery are on this limestone. Beyond this the road passes on to harder white limestone with various species of *Lepidocyclina*, probably of Oligocene and Upper Eocene age. Several large sink-holes or cockpits, up to 100 yards in diameter, were seen in this limestone, which shows other karst features such as enlarged joints or grikes, and the pitting and fretting of upstanding outcrops by rainwater.

Farther on, about 500 yards north of Green Bay, the road passes on to dolomite, in which small bodies having the appearance of *Dictyoconus* sp. were found, but their finer structures have been destroyed by recrystallisation. However, there can be no doubt that this represents the Troy Limestone of Middle and Upper Eocene age which, as Mr. Versey has shown, is often dolomitised. A short distance beyond this point the party came within sight of Green Bay.

As explained above, the eastern half of the anticline or dome has disappeared, primarily as a result of faulting, which has brought to light the older rocks forming the core. These offered less resistance to marine erosion than the dolomite or limestone, so the sea has cut back into them to form Green Bay.

The road turns west for a quarter-mile, still on dolomite, and then south again along the back of the bay. Here the excellent exposure of the older rocks, first discovered by Matley, at a height of about 300 feet above sea-level, was seen. The road-cutting shows a continuous section through the core of the anticline, the older rocks being exposed for a distance of eighty-six yards. These rocks are metamorphic, comprising chiefly hornblende-schists and epidiorites; fragments of other schists, gneisses and granulites have been found on the overgrown slopes below the road. It was observed that the metamorphic rocks are directly overlain by the White Limestone Formation, the basal bed of which is a soft, chalky white marl some three feet thick, succeeded by about ten feet of compact buff limestone, permeated with many veins of fibrous calcite or travertine resembling the 'beef' in the Lias of Lyme Regis. Above this comes a massive dolomitic breccia forming the lower part of the Eocene dolomite series.

Similar schists, epidiorites and gneisses are known in the Blue Mountains, but there they are thought to be separated from the White Limestone by thousands of feet of Cretaceous and Lower Eocene beds. The direct superimposition of the Middle or Upper Eocene limestone on the Metamorphic Series in the Green Bay area has led to considerable controversy as to the age of the older series and the nature of the junction, the chief protagonists being Dr. C. T. Trechmann and the late Dr. C. A. Matley.

The dip of the foliation of the schists in the road-cutting is roughly concordant in direction with that of the overlying limestones. In the axis the schists are contorted, and pierced by two thin porphyry dykes. Northwards the foliation dips at 24° to 28° NE., parallel to the dip of the overlying white marl. Southwards the dips are more variable, being 40° near the axis, then decreasing to 30° and 25° , and again increasing to a maximum of 47° at the southern end of the outcrop; the direction of dip is approximately SW. The overlying beds show no such variations in dip, but arch over the metamorphic core in an even curve, and at the southern end the white marl, dipping at only 10° to 15° SW., rests upon the truncated edges of the steeply dipping folia of schist.

The party drove back to the road-bend, parked cars, and clambered down the steep track, past the now overgrown site of the Lazaretto buildings, to the beach. At the northern end of the bay the section first described by Trechmann was studied. The lowest visible rocks consist of amphibolite and hornblende-schist, with lenticles of hard limestone and streaks of other metamorphic rocks, the total thickness exposed being over fifty feet. At the northern end of this outcrop a wedge-shaped bed of crystalline marble, hard, grey, streaked and glistening, rests on the schists. It has a maximum observable thickness, at the base of the cliff, of three feet, but thins upwards and ends at eight feet above the beach. Its lower surface, which appears to be conformable to the schists, dips at 57° NE., its upper surface at only about 40° NE.

The succeeding bed is a breccia twelve inches thick, with angular fragments of amphibolite, granulite, schist and marble in a dolomitic matrix. This bed dips at 40° NE., levelling to 15° near the beach, and rests on the marble, to which it is cemented, but oversteps on to the schist in the upper part of the cliff. The fragments have not moved far from their source; where the breccia rests on the schist only schist fragments are present, and where it rests on marble, while many small schist fragments occur, large marble fragments predominate. Above the breccia is a thin bed of dolomite, first discovered by Trechmann. An examination of this shows that it also contains many angular grains of rocks and minerals, up to 3 mm. in diameter, including amphibolites, granulites, quartz, magnetite, sphene and apatite. This bed is succeeded by twelve feet of bluish-green clay, above which lies the travertine limestone and the dolomitic breccia as in the road-section.

Members discussed the controversy between Matley and Trechmann as to the age of the metamorphic series and its relationship to the Tertiary limestone. Matley believed the metamorphic rocks to be Palaeozoic or Pre-Cambrian, and the relationship to be an unconformable one. According to Trechmann the schists represent the Carbonaceous Shale (Lower Eocene), while the streaks of grey limestone near their top may be altered

parts of the Yellow Limestone (Middle Eocene). He doubted the existence of an unconformity, but if present it would be a minor one between two phases of Eocene deposition. He regarded the metamorphic core as a 'sort of intrusion', the marble as a metamorphosed basal bed of the White Limestone and the dolomitisation of the overlying thin band as due to contact alteration. He believed that all these metamorphic effects were caused 'by heated material (activating gases) below, acting like an intrusion, and this material has been unable to penetrate far up into the pure limestone or to alter it except by marmorising and dolomitising the layer at the base'.

The evidence does not seem to confirm these opinions. Dolomitisation is not confined to the basal layer of the White Limestone, indeed the lower 350 feet of this formation are dolomitic. Further, it is not a local phenomenon, dependent upon the presence of metamorphic or igneous rocks below. It occurs also over extensive areas of central Jamaica, where the dolomite is underlain by great thicknesses of sedimentary rocks of Middle Eocene or Cretaceous age, so the dolomitisation is clearly not of metamorphic origin.

It was remarked that the superimposition of the basal bed of the White Limestone on the truncated edges of the steeply dipping folia of schist in the road-cutting is clear evidence of unconformity. Even stronger proof was provided by the breccia at the base of the White Limestone Formation in the cliff-section, with its angular fragments of schist and marble in an unmetamorphosed matrix. Evidently the marble is part of the older series and cannot be regarded as a metamorphosed basal bed of the White Limestone. This older series must have been metamorphosed, presumably at great depth, and laid bare by erosion before the deposition of the White Limestone. This indicates a considerable lapse of time between the formation of the two series, so it is unlikely that the older one will be as recent as Lower or Middle Eocene.

However, there is no need to accept Matley's view that the older rocks are Palaeozoic or Pre-Cambrian in age. This view was based on a false premise, that the last major orogeny in Jamaica before the Alpine was the Hercynian revolution of Late Carboniferous times. This is no doubt true in Britain and Europe, but not in the Western Hemisphere where the Laramide Revolution of late Cretaceous and early Eocene times intervened. This orogeny was active in Jamaica and would have been quite competent to effect the metamorphic changes observed, so the rocks themselves may well be as late as Cretaceous in age.

After a late lunch the party walked along the beach to the southern end of Green Bay. Here there is no dolomite, the rocks consisting of a limestone breccia with a pink matrix. The age of this rock is thought to be Uppermost Eocene or Oligocene, the dolomite having been removed by faulting

and marine erosion. The cliff from this point southwards to Fort Clarence is probably a fault scarp.

The party returned to the cars and drove back to Kingston, arriving at about 5 p.m.

REFERENCES

- CHUBB, L. J. 1954. The Lazaretto Section, Jamaica. *Colon. Geol. min. Resour.*, **4**, 233-47.
———. 1956. The Correlation of the Jamaican Cretaceous. *XX Session Int. geol. Congr. Mexico* (in press).
MATLEY, C. A. & F. HIGHAM. 1929. The Basal Complex of Jamaica with special reference to the Kingston District. *Quart. J. geol. Soc. Lond.*, **85**, 458-9.
MATLEY, C. A. 1936. The Basal Complex in Jamaica—a reply. *Geol. Mag.*, **73**, 331-3.
———. 1937. The Age of the Jamaica Granodiorite and its Associated Rocks. *Geol. Mag.*, **74**, 503-4.
———. 1951. *Geology and Physiography of the Kingston District, Jamaica*. London.
TRECHMANN, C. T. 1936a. The Basal Complex Question in Jamaica. *Geol. Mag.*, **73**, 261-2.
———. 1936b. The Complex Question in Jamaica. *Geol. Mag.*, **73**, 382.
———. 1942. Metasomatism and Intrusion in Jamaica. *Geol. Mag.*, **79**, 161-78.
———. 1945. *The West Indies and the Mountain Uplift Problem*. West Hartlepool.

Field Meeting at Bath in St. Thomas, Jamaica

JAMAICA GROUP

2 February 1958

Report by the Director: L. J. CHUBB

THIS MEETING was originally planned for 26 January, but was postponed owing to rain. Its main purpose was to visit the section where fossiliferous Cretaceous rocks were first recorded in Jamaica by Lucas Barrett in 1860, and to study the hot and cold springs that supply the Bath of St. Thomas the Apostle.

Twenty-three members and friends drove eastwards from Kingston along the coastal road which beyond Bull Bay follows the continuation of the Wag Water Thrust. This thrust traverses the island from north-west to south-east, forming the south-western boundary of the Port Royal Mountain belt, and at its southern end swings round towards the east becoming a coastal fault. The parallel Yallahs Thrust, which separates the Port Royal Mountain belt from the Blue Mountain massif, also swings eastwards, past Woburn Lawn and Cedar Valley and along the line of the Negro River to Trinity Vale, thence across the Morant River to the Plantain Garden River, which it follows to its mouth in Holland Bay. The village of Bath lies in this valley.

At Morant Bay, some thirty-one miles from Kingston, the party turned left and drove northwards on a road that crosses the eastern continuation of the Port Royal Mountain belt, ascending the dip-slope of the Tertiary White Limestone Formation, and reaching an elevation of 1000 feet at Wilmington. Beyond this point it descends the scarp face, and at about a mile short of the Potosi cross-road the base of the White Limestone was seen, with a thick bed of conglomerate below it. Half a mile farther, in a stream bed under a bridge, a lower horizon was examined, consisting of an alternation of conglomerates, sandstones and shales, evidently representing the Lower Eocene Richmond Beds or Carbonaceous Shale. The dip is steep, about 80° N., no doubt due to the proximity of the great thrust-fault in the Plantain Garden River Valley, which is only half a mile away. There was some discussion as to whether the succession in these beds was reversed, but a study of the graded bedding showed it to be normal.

At Potosi cross-roads the party drove west for a couple of miles, through Sunning Hill, to a bridge over the Plantain Garden River. The contrast was noted between the precipitous slopes of the upthrust Cretaceous rocks on the north side, which rise abruptly to 1500 feet or more, forming the

southern margin of the Blue Mountain Massif, and the gentle slopes of Lower Eocene rocks on the south side, only some 250 to 500 feet above sea-level.

North of the bridge a section was examined which appears to be that described by Lucas Barrett, Director of the West Indian Geological Survey in 1860. He described it as showing 'a bed of compact limestone, eight feet thick, resting on a thick bed of conglomerate, and overlaid by shale. . . . The limestone contains numerous fossils, all of them characteristic of Cretaceous or other Secondary strata, viz. *Inoceramus*, *Hippurites*, and *Nerinea*.' These rocks had been referred by De la Beche (1827, 143) to the Transition Series (Lower Palaeozoic). No fossils were found by the party, as the limestone has been thickly covered with calcareous tufa by a waterfall which flows over it. A neighbouring section described by Barrett, consisting of vertical limestone bands alternating with shale, was sought in vain. It is probably now concealed by a retaining wall on the bank of the Plantain Garden River.

The party drove back through Potosi to Bath, and thence took the road which goes north through Cretaceous shales and marbles for a mile and a half up the valley of the Sulphur River to Bath Hotel, where lunch was taken. The father of Sir Henry De la Beche, founder of the British Geological Survey, died here in 1801, having with him his son, then five years old.

After lunch members walked up the valley behind the hotel to see the hot and cold springs that feed the mineral baths. Most of these springs are entombed, and the water passes through conduits to the hotel. The temperature of one of the hot springs was found to be 125°F., two degrees lower than that recorded by De la Beche 130 years ago (1827, 153), and a strong smell of sulphur dioxide was noticed. The salinity and radioactivity are less than those of the Milk River Baths in Clarendon parish, but the high sulphate content of the hot springs suggests that they are in part of juvenile origin (White, 1957a). The cold springs, however, are poor in sulphate but rich in carbonates, indicating that their source is meteoric water which has percolated through calcareous rocks. Both the hot and cold springs are rich in chlorides probably derived from sea-water, but as they are nearly 500 feet above the present sea-level, this can only be due to admixture with connate water trapped in the Cretaceous sediments (White, 1957b).

After a short visit to Bath Botanical Gardens the party drove west through the village and along the road which winds up the valley of the Island River towards Corn Puss Gap. The road-cuttings show conglomerates and shales, which break with glossy surfaces, so that they might be called phyllites, interbedded with which there are outcrops of white, grey, pink or lilac marble, some beds being of considerable thickness. Probably the metamorphism of these Cretaceous rocks was due to the intense pressure

and heat they suffered during the later phases of the Laramide orogeny, when they were pushed up over the Eocene rocks on the Yallahs-Plantain Garden thrust-fault.

The party returned to Kingston via Port Morant and the coastal road.

REFERENCES

- BARRETT, L. 1860. On some Cretaceous Rocks in the south-eastern portion of Jamaica. *Quart. J. geol. Soc. Lond.*, **16**, 324-6.
- DE LA BECHE, H. T. 1827. Remarks on the Geology of Jamaica. *Trans. Geol. Soc. Lond.* (2), **2**, 143-94.
- White, D. E. 1957a. Thermal Waters of Volcanic Origin. *Bull. geol. Soc. Amer.*, **68**, 1637-57.
- . 1957b. Magmatic, Connate and Metamorphic Waters. *Bull. geol. Soc. Amer.*, **68**, 1659-82.

Palaeomagnetism of the Younger Gabbros of Aberdeenshire and its Bearing on their Deformation

by D. J. BLUNDELL and H. H. READ

Received 30 April 1958

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ABSTRACT: The directions of magnetisation of gabbros from all the large Younger Basic masses in Aberdeenshire are found to be essentially the same. Any post-consolidation folding of these masses, as proposed by some workers, is therefore unlikely to have occurred. Precautions considered to be necessary in the collection of samples of basic igneous rocks for palaeomagnetic investigations are discussed.

1. INTRODUCTION

AT THE BEGINNING of this century it was discovered that igneous rocks possessed a remanent magnetisation of great stability. This phenomenon was used by a number of workers in an attempt to retrace the magnetic field of the earth in geological time, chief amongst whom was Konigsberger. In 1938 he was the first to point out that the remanent magnetisation of an igneous rock was probably acquired when the rock cooled and that it was directed along the earth's field acting at that time. Roche (1950), working on successions of recent lavas in the Plateau Centrale, demonstrated that the flows are magnetised, on the average, not along the earth's present field but in the direction of a field due to a supposed magnetic dipole located at the centre of the earth and directed along its rotational axis. Hospers (1954) considerably strengthened this interpretation in his systematic research on recent Icelandic plateau lavas, when he found that the rocks were magnetised on the average in the direction of the geographic

North Pole with an inclination downwards appropriate to the axial dipole field.

As a result of a systematic investigation of the magnetic properties of the New Red Sandstones in England, Clegg, Almond & Stubbs (1954) were able to show that the rocks were magnetised along a NE.-SW. axis with a shallower inclination than the earth's present field. Creer, Irving & Runcorn (1954, 1957) have measured the directions of magnetisation of many British rocks of various ages. They have presented the palaeomagnetic data indicating the direction of magnetisation for rocks from Miocene to Pre-Cambrian and the inferred pole positions at a number of times since the deposition of the Lower Torridonian Sandstones of Scotland. It is clear that these results have an important bearing not only on the theory of continental drift but also on the possibility of more humble movements, one of which is the concern of this paper.

The usefulness of rock magnetism in the solution of any geological problem is governed by the need to demonstrate that the magnetisation measured in the laboratory is a true record of that acquired by the rock when it was formed. In igneous rocks, the magnetisation can in appropriate cases be shown to be of thermo-remanent origin, acquired when the rocks cooled from above the Curie point of the ferromagnetic minerals concerned. Any subsequent metamorphism would naturally modify this magnetisation. A number of stability criteria, by which the constancy of direction of magnetisation of a rock can be demonstrated, are fortunately available.

Blundell (1957b) has utilised the magnetic properties of rocks to investigate a number of geological problems in order to illustrate the use of palaeomagnetism in geology. Among these problems was that concerning the possible deformation of the large gabbro bodies in north-east Scotland, investigated in the main by Read. This account is put together not only for its relevance to this particular question but also to direct attention to a variety of precautions that seem to be necessary in collecting material for palaeomagnetic study.

2. EXPERIMENTAL PROCEDURE

Orientated samples were collected large enough to provide at least two cube specimens of two centimetre side; the distinction between sample and specimen is the general practice and is followed in this paper. Before removal from the exposure, the sample was marked on its upper surface with an arrow directed towards the magnetic north as observed by using a prismatic compass. Horizontal lines were marked on two adjacent vertical faces of the sample, preferably at right angles to one another, by use of a spirit-level. With this technique samples were correctly orientated to within three degrees.

From the samples, cubes of two centimetre side were prepared by first cutting a two centimetre thick slice parallel to the horizontal markings, transferring the arrow markings to this slice and then cutting the final four faces. By this procedure, cubes accurate to within half a millimetre could be quickly obtained. Errors in orientation of the cubes with reference to the *in situ* orientation in no case exceeded 5° . Since there was statistical variation in directions of magnetisation in the rocks investigated greater than this, there was no need for a more accurate technique. Both Robertson (1947) and Graham (1949) have shown that rocks possessing stable magnetisation are unaffected in the process of removal of the samples and the preparation of the cubes therefrom.

Blundell (1957a) has described the experimental procedure: 'Before measurement of the magnetisation of the specimens was made, the samples were "stored for a month in the present earth's field orientated as they occurred *in situ*. After measurement, each one was turned through 180° about an E.-W. axis, to lie for another month, and was then re-measured. This process served two purposes: first, the mean of both measurements removed isothermal and viscous magnetisation, leaving only the natural remanent magnetisation which was derived from the original thermo-remanent magnetisation acquired during the formation of the (rock); second, it is a standard method of testing the stability of the remanent magnetisation, since those specimens whose direction of magnetisation altered greatly between the two observations are probably unstable. A further test of stability is afforded by the calculation of the value Q_N , the ratio of natural remanent magnetisation to induced magnetisation.'" Dutt (1955) showed that for the Mull lava flows, the greater the value of Q_N the greater is the stability of magnetisation' (Blundell, 1957a, 188-9). If the value of Q_N is greater than unity, the magnetism of an igneous rock is clearly of thermo-remanent origin, since it is unlikely that the earth's field was ever much greater than it is today.

The magnetisation was measured on a spinning magnetometer designed by Bruckshaw & Robertson (1948) and modified by Vincenz (1952). The cubes were rotated about all three axes, thus allowing a check on the accuracy of the observations. The initial susceptibility, employed in the determination of the quantity Q_N already mentioned, was measured on an instrument built by Bruckshaw & Robertson on the same principle as their spinning magnetometer.

3. THE SUPPOSED DEFORMATION OF THE YOUNGER GABBROS OF NORTH-EAST SCOTLAND

The Younger Basic intrusions of Aberdeenshire form one of the most distinctive igneous provinces of Scotland. In date, they are later than the

regional metamorphism of the Dalradian country-rocks but earlier than the deposition of the local Middle Old Red Sandstone. They make half a dozen large and many small bodies of igneous rock that are united by such provincial characters as their dominant gabbroic composition, the occurrence of peridotitic and troctolitic derivatives often banded, the abundance of noritic types and the common development of contaminated varieties. The chief intrusions of the province are shown in Fig. 1. Since 1914, many of them have been studied in whole or in part and a considerable body of knowledge is accumulating about them (Watt, 1914; Read, 1921, 1923a, 1923b, 1924, 1931, 1935, 1951, 1952, 1956; Read & Farquhar, 1952; Stewart, 1946; Whittle, 1936; Sadashivaiah, 1950, 1954a, 1954b; Shackleton, 1948). There can be little doubt that all these basic bodies belong to one igneous event and possibly form together a great sill-like body miles thick and hundreds of square miles in lateral extent.

The Dalradian country-rocks of these intrusions are metamorphic rocks, originally sediments, varying in grade from slate to regional gneisses of different types and origins. In appropriate situations, the country-rocks are thermally contact-metamorphosed by the gabbros with the production of normal hornfelses of static types. According to Read (1955) the metamorphosed Dalradian rocks are arranged in a gigantic recumbent anticline closing south-eastwards and itself affected by subsidiary broad structures, one of which is the Buchan Anticline (Read & Farquhar, 1956). Resting unconformably on the Dalradian are outliers of Old Red Sandstone sediments which contain material derived from the Younger Basic suite (Read, 1923b; Hinxman & Wilson, 1890). The western margins of some of these outliers are formed by faults and their rocks are broadly folded (Read, 1923b).

In three of the basic masses, Belhelvie, Huntly and Inch, banded and other structures occur, some of which have been used to propose an overturning of the gabbro masses since their consolidation. In the Belhelvie mass, Stewart (1946) observed rhythmic banding along the western part of the mass in troctolite, hypersthene-gabbro and western olivine-gabbro. The banding is considered to be due to the accumulation under the influence of gravity of the early formed crystals during the consolidation of the magma and to be originally more or less horizontal in attitude. Stewart favours the opinion that the banded rocks have undergone a considerable post-banding tilting, even though the floor of the chamber may have had an initial dip. Since the sedimentation characters of the Belhelvie bands indicate younging to the east, Stewart's opinion requires a 50° to 90° tilt from west to east about a north-south axis. In the peridotite and troctolite of the western part of the Huntly mass, Shackleton (1948) has shown that the rhythmic banding strikes north and south and dips westwards at 70° . On sedimentation characters acquired during the settling of the heavy

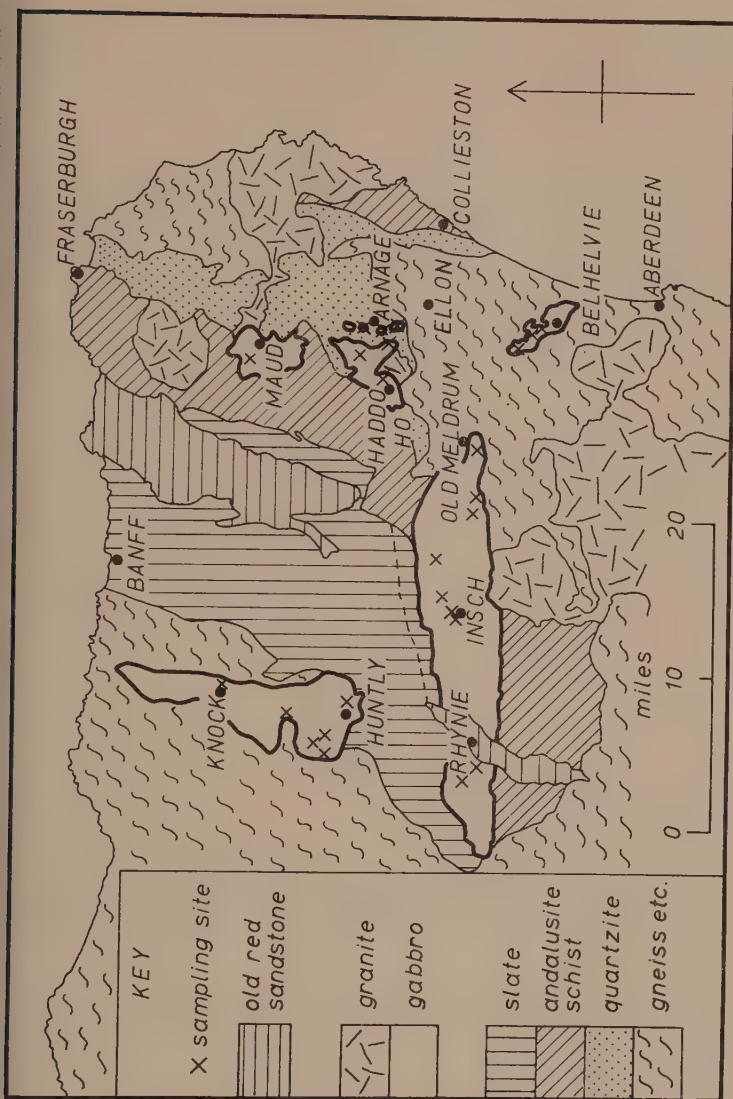


Fig. 1. The Basic Masses of North-East Scotland, with sampling sites of investigated specimens

crystals, Shackleton considers that the banded rocks of the Huntly mass young or face eastwards and are thus overturned; he concludes that this overturning took place when the gabbros were rigid and is thus a tectonic phenomenon. For the Belhelvie and Huntly masses, therefore, tilts of 90° or more from west to east about a north and south axis are proposed after the consolidation of the gabbro magma.

The Insch banded gabbros do not supply evidence of the quality of that from Belhelvie and Huntly. In the eastern end of the Insch Mass, Sadasivaiah (1954a) described peridotites, troctolites and olivine-gabbros, that from their limited outcrops available seemed to run in north-south bands and, in some exposures, small-scale banding that appears to be steep can be seen. Other evidence, not yet published, derived from the attitude of the large-scale differentiates of the olivine-gabbro of the Insch mass, shows that the original uppermost part of the Insch differentiated mass is still uppermost—no tilting in the Insch mass as a whole can have taken place.

These data have been assembled by Shackleton (discussion to Read & Farquhar, 1956) to form Fig. 2. From them, he deduces a large-scale post-gabbro folding responsible for the overturning of the originally flat banding of the Huntly and Belhelvie masses with, of necessity, the formation of the Buchan Anticline in the Dalradian rocks and the upending of the pile of

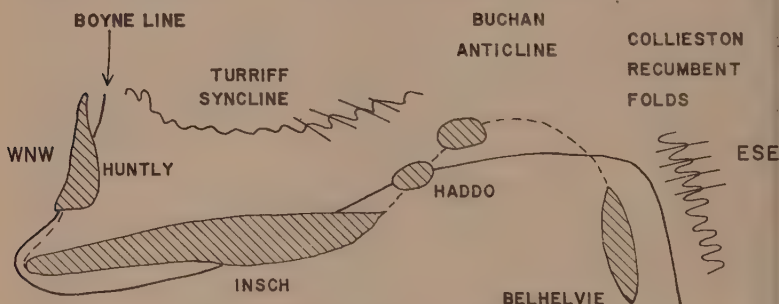


Fig. 2. Professor Shackleton's interpretation of the attitude of the Basic Masses of North-East Scotland. (Reproduced by permission of the Council of the Geological Society from *Quart. J. geol. Soc. Lond.*, **112**, 115)

small-scale recumbent folds of Collieston (see Fig. 2). Read (discussion to Read & Farquhar, 1956) was unable to accept this post-consolidation folding of the basic masses. There was no doubt that the Dalradian country-rocks had undergone as part of their major structure a small-scale tight folding that was earlier than the regional metamorphism, this being of a static post-kinematic type characterised by andalusite and cordierite. Shackleton (discussion to Stewart, 1946, p. 498, and 1948) had suggested that the change of attitude was largely achieved by distortion. The gabbros

of this province abound in delicate textures such as reaction rims, dactylitic intergrowths and the like, and intricate textures are present in the abundant contact-hornfels and the country-rocks generally. The perfect preservation of such textures indicated to Read (Read & Farquhar, 1956) that no post-consolidation overturning, achieved by distortion, had occurred. Further, he found it difficult to accept the separation of the broad 'Buchan Anticline' folding from the main recumbent folding of the Banff Nappe by a considerable interval during which the Younger Basic gabbros were intruded. It may be recalled that the Middle Old Red Sandstone of north-east Scotland shows in places a degree of folding. This post-Old Red Sandstone folding appears to Read to be of a shallow type unlikely to have affected the rigid gabbros and basement on which the outliers lie. In 1958, Shackleton reaffirmed his opinion that the Banff Nappe and the basic sheet intruded in it had been deformed by movements which produced steeply monoclinical zones (1958, 392).

The controversy outlined above is clearly one that might be settled by the application of rock magnetism. The Younger Basic rocks may be considered to be of Caledonian origin and probably of Lower Palaeozoic age. Creer *et al.* (1954) had measured the direction of magnetisation of the Cambrian Caerbwdy Sandstone of South Wales and found it to be directed southwards with 40° downward inclination. If the Aberdeenshire gabbro masses were in their original positions relative to one another, they should all have this direction of magnetisation, but if any masses had been turned about a NNE.-SSW. axis through about 100° as indicated in Shackleton's diagram, such masses would have a direction 60° W. of S. and downward inclination of 10° . These directions are 65° apart. Thus it was considered that the two possibilities might be resolved. If Shackleton's hypothesis was correct, then samples from Huntly and Belhelvie would be magnetised in a direction 60° from that of samples from the Inch, Haddo House and Arnage masses; if Read was correct all samples should be magnetised southerly with 40° downward inclination. It was of course realised that if, at the time the gabbro magma consolidated, the earth's field was directed along the axis of the postulated folding, the method of testing would be invalid, since no change of direction of magnetisation would have occurred. A further requirement was the demonstration that the magnetisation was acquired by the rocks during consolidation and had remained unaltered in direction up to the present time.

4. THE SAMPLING AND THE GEOPHYSICAL AND GEOLOGICAL CONTROLS OF THE VALID SPECIMENS

It will be recalled that samples are the orientated pieces of rock collected at a site and specimens are the individual cubes or cylinders cut from the

samples. The sampling sites in the different masses are indicated in Fig. 1. Twenty-six sites yielded sixty samples which were examined petrographically and geophysically to determine their suitability for palaeomagnetic purposes. The sites and the controls governing the selection of specimens from them are now detailed.

(a) The Huntly Mass

In this mass, samples, totalling fourteen in number, were collected from Bin Hill Quarry, three miles NW. of Huntly, in banded olivine-gabbro; from Sinsharnie Quarry, one half-mile N. of Bin Hill, in troctolite and peridotite, the latter mostly serpentinitised; from Craighead Quarry, one mile W. of Huntly, in partly serpentinitised peridotite; from Battlehill Quarry, Huntly, in gabbro; from Rothiemay Railway Cutting in heavily serpentinitised peridotite, and from the great Ternemny Quarry near Knock, eight miles N. of Huntly, in fresh biotite-norite. The rock in Battlehill Quarry is clearly greatly deformed and fractured and in slice proved to be partly of contaminated origin (cf. Read, 1923b)—the samples were rejected for palaeomagnetic purposes.

(b) The Inch and Cabrach Masses

These masses can be considered as originally one, now separated by the post-Middle Old Red Sandstone faulting in the Bogie Valley. Eighteen samples were collected from eight sites in these masses. The largest collection came from Pitscurry Quarry near Pitcaple and from Cuttlecraigs Quarry, a mile E. of Pitscurry. These rocks are gabbros, norites and granular gabbros, often greatly deformed and in places essentially mylonitic. Read (1956) has shown that the south-western margin of the Inch Mass is formed by a shear zone along which the country-rocks in the south have moved upwards relative to the igneous body and that similar shear-belts traverse the gabbros in the Inch and Ledikins areas (Read, 1956). Further, nearer Pitscurry and Cuttlecraigs, the same author (Read, 1951) has described the production of cataclastic and mylonitic rocks in weak elements in the gabbros and country-rocks of the Pitcaple area. When examined for their magnetisation, the samples from Pitscurry and Cuttlecraigs showed a wide variation in their inclination, possibly not resulting entirely from instability but from disorientation brought about by the shear movements. The upwarping of the southern boundary of the Inch Mass could account for the low inclination values observed. All the samples from the two quarries were finally rejected.

A sample from Fallow Hill, though having a magnetisation apparently stable and in agreement with other stably magnetised samples, was rejected on account of decomposition due to weathering.

(c) The Belhelvie Mass

Three sites were sampled in this mass (Stewart, 1946), namely, Craigie Quarry, Beauty Hill Quarry and large solid outcrops on Harestone Moss. These provided olivine-gabbro, troctolite and peridotite, the more ultrabasic types being partly serpentinised but showing no signs of mechanical deformation.

(d) The Haddo House Mass

Collections from the Haddo House mass illustrated the hazards of sampling gabbros for palaeomagnetic purposes. Although ten samples were collected, only one was finally considered to be truly *in situ*. This was the biotite-norite in contact with calcareous country-rock exposed in the quarry at Michael Muir on the east edge of the Haddo House body (Read, 1935). Much of the Haddo House mass is exposed as residual boulders, satisfactory it is believed for mapping purposes but useless for palaeomagnetic studies. These boulders vary in size up to forty feet in length but are generally only about ten feet long. It can be demonstrated in some places that what looked like a good *in situ* outcrop is really, when uncovered, a group of large boulders only roughly in place. Such boulders are in place to the extent that they have probably not moved more than a few inches or feet from their original positions, but in doing so they have of course become disorientated. The evolution of the residual boulders can be seen to be controlled by the characteristic exfoliation-weathering of the gabbros. As the various layers peel off, a residual core of fresh massive gabbro is left sitting in the soft, fragmented, weathered material. Settling and rotation could then take place relatively easily and in this manner very large boulders become disorientated. Even in seemingly solid unmoved crags, movement on widened joint surfaces is possible. The magnetic measurements of the Haddo House boulders appear to indicate a rotation about a vertical rather than a horizontal axis, possibly due to the prolate shape of the residuals.

(e) The Arnage Masses

In the small Arnage masses, nine samples were collected from exposures in cuttings of the Ellon to Fraserburgh railway line. The rocks from three sites were not truly magmatic material and from two others were highly contaminated (Read, 1923a; Read & Farquhar, 1952). The four pure magmatic samples came from Little Arnage, Arnage Station and Towie Wood and were norites as described by Read (1923a). Although not specified in Shackleton's original hypothesis, the Maud mass would presumably be placed in much the same position as the Haddo House and Arnage masses. Two samples, a quartz-gabbro and a norite, were obtained from a quarry and a crag near Mill of Fedderate, a mile north-west of Maud; there was little doubt that the crag was solidly in place.

The intensity and direction of magnetisation and the susceptibility of the specimens were measured in the usual way and stability tests were carried out. Most samples were magnetised at right angles to the direction of the present earth's field, which gives evidence for some stability. As has been mentioned, there was a general tendency for rocks in which deformation had occurred to be unstable. The same appeared to be true for samples affected by end-stage processes, the low-temperature operation in which pyroxenes have been altered to colourless hornblendes arranged in clusters of small blades (Read, 1935). High-temperature reactions had no obvious effect on the magnetic stability. No correlation could be found between degree of serpentinisation of the peridotite samples and their stability of magnetisation—of the ten samples collected four were unstable. These observations on the relationship of stability to petrogenetic history are of course tentative, but they might be borne in mind in future work on palaeomagnetism in basic igneous rocks. Nine samples, all of them unaltered and undeformed gabbros, norites or peridotites, were found to be unstable to varying extents. Finally, twenty-one samples of fresh magmatic rock, apart from serpentinisation in peridotite, satisfied the stability criteria and were used in the palaeomagnetic tests.

5. THE MAGNETIC RESULTS

The general magnetic results for the stable rocks are summarised in the Table below. In Fig. 3 the directions of magnetisation of the stable specimens and the mean directions for each mass are shown. The single useful sample from Haddo House has been grouped with those from Arnage. Since the two masses are close together, with no suggestion of relative movement, this is considered to be legitimate.

Mass	No. of samples	Azimuth ø mean	Inclination I mean	Konigs- berger Ratio Q_N mean	Circle of confidence, radius	Distribu- tion Factor K
Huntly	6	192° E. of N.	+60° down	2.1	8°	20
Insch	5	176	+48	0.7	14°	10
Arnage	4	186	+39	18.4	12°	13
Haddo House	1					
Belhelvie	3	174	+56	2.1	8°	24
Maud	2	177	+50	2.1		
All samples	21	182	+51	5.3	5°	13

It will be noted that values of Q_N for the norite samples from Arnage were considerably higher than those for any of the others. Nagata (1933, 125) has reported finding two rock samples from the same gabbro having the same susceptibility but differing by a factor of twenty in intensity of

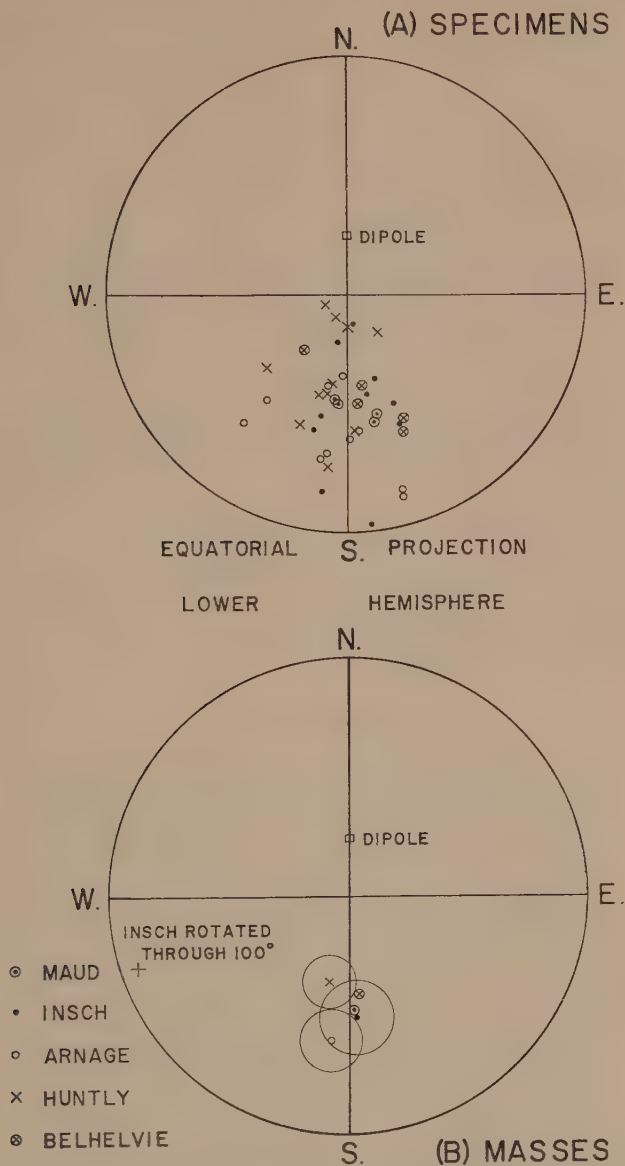


Fig. 3. Schmidt Equal Area Projections showing the Directions of Remanent Magnetism, (a) stable specimens, (b) mean directions for the Masses with circles of confidence

magnetisation. He found that the strongly magnetised rock contained both maghemite and magnetite, the weakly magnetised one only magnetite. Whether this holds for the Arnage rocks remains to be investigated.

The statistical analysis proposed by Fisher (1953) has been used to obtain the circles of confidence, radius α , calculated at the 33% probability level using samples as statistical units, for the Huntly, Inch and Arnage (with Haddo House) masses. The results are plotted in Fig. 3. The distribution factor K has also been calculated for each of the masses.

With the use of Watson's (1956) extension of Fisher's statistical analysis, a test was made of the hypothesis that the mean directions of magnetisation of the three sample populations from Huntly, Inch and Arnage-Haddo House were identical. Watson has shown that for three populations

$$\{\sum(R_i - R)/(N - \sum R_i)\} \cdot \{2(N-3)/4\} = F_{4,Z(N-3)}$$

where N denotes the total number of samples, R the vectorial sum of all the magnetisation directions and R_i the vectorial sum of the directions in the i^{th} population. $F_{4,Z(N-3)}$ is the statistic of the F test for equality of variances with minimum and maximum degrees of freedom of 4 and $z(N-3)$.

The calculated value of $F_{4,26}$ was 1.50, significantly less than the tabulated value at the 5% probability level of 5.76, thus indicating that there is no significant difference between the mean directions of the remanent magnetisation of the three sets of samples.

6. CONCLUSIONS

On the assumption that the Inch mass remains horizontal, then the Huntly mass, if overturned according to Shackleton's hypothesis, should have a magnetisation 70° from the direction actually observed in samples from Huntly. The possibility that such a difference is fortuitous is very small, being less than one per cent. The magnetisation of samples from Belhelvie is in full agreement with that from the other masses. Since the samples used in the statistical analyses were all of unaltered undeformed magmatic material, there is little likelihood that the rocks acquired their magnetisation after any supposed folding. The Q_N values have indicated that the magnetisation was thermo-remanent in origin and there was no sign of the samples having suffered any thermal metamorphism subsequent to their original intrusion and consolidation.

It must be concluded from this evidence that the folding suggested by Stewart and Shackleton is most unlikely to have occurred. There is no significant difference between the magnetisation of any of the basic masses, and it is therefore suggested that they have remained relatively undisturbed since their formation. The mean distribution of magnetisation of all the

stably magnetised samples is in general agreement with Creer's value for the Caerbwdy Beds and congruent with the intrusion of the Aberdeenshire gabbros as part of the Caledonian drama.

REFERENCES

- BLUNDELL, D. J. 1957a. A Palaeomagnetic Investigation of the Lundy Dyke Swarm. *Geol. Mag.*, **94**, 187-93.
- . 1957b. Some Geological Applications of Rock Magnetism. *Ph.D. Thesis, University of London*.
- BRUCKSHAW, J. M. & E. I. ROBERTSON. 1948. The Measurement of the Magnetic Properties of Rocks. *J. sci. Instrum.*, **25**, 444-6.
- CLEGG, J. A., MARY ALMOND & P. H. STUBBS. 1954. The Remanent Magnetism of some sedimentary rocks in Britain. *Phil. Trans.*, Ser. 7, **45**, 583-98.
- CREER, K. M., E. IRVING & S. K. RUNCORN. 1954. The Direction of the Geomagnetic Field in remote epochs in Great Britain. *J. Geomagn. Geoelect.*, Kyoto, **6**, 163-8.
- . 1957. Geophysical Interpretation of Palaeomagnetic Directions from Great Britain. *Phil. Trans.*, Ser. A, **250**, 144-56.
- DUTT, S. K. 1955. The Mull Lavas and their Magnetism. *Ph.D. Thesis, University of London*.
- FISHER, R. A. 1953. Dispersion on a Sphere. *Phil. Trans.*, Ser. A, **217**, 295-305.
- GRAHAM, J. W. 1949. The Stability and Significance of Magnetism in Sedimentary Rocks. *J. geophys. Res.* **54**, 131-67.
- HINXMAN, L. W. & J. S. G. WILSON. 1890. Central Aberdeenshire. *Mem. geol. Surv.*, U.K.
- HOSPERS, J. 1954. Reversals of the Main Geomagnetic Field, III. *Koninklijke Nederlandse Akademie van Wetenschappen, Proceedings, Series B*, **57**, 112-20.
- KONIGSBERGER, J. G. 1938. Natural Residual Magnetism of Eruptive Rocks. *Terr. Magn. atmos. Elect.*, **43**, 119-30, 299-320.
- NAGATA, T. 1953. *Rock Magnetism*. Maruzen, Tokyo.
- READ, H. H. 1923a. The Geology of the Country round Banff, Huntly and Turriff. *Mem. geol. Surv. U.K.*
- . 1923b. The Petrology of the Arnage District in Aberdeenshire: a study in assimilation. *Quart. J. geol. Soc. Lond.*, **79**, 446-86.
- . 1924. On certain Xenoliths associated with the contaminated rocks of the Huntly mass, Aberdeenshire. *Geol. Mag.*, **61**, 443-54.
- . 1931. On Corundum-Spinel Xenoliths in the Gabbro of Haddo House, Aberdeenshire. *Geol. Mag.*, **68**, 446-53.
- . 1935. The Gabbros and Associated Xenolithic Complexes of the Haddo House district, Aberdeenshire. *Quart. J. geol. Soc. Lond.*, **91**, 591-638.
- . 1951. Mylonitisation and cataclasis in Acidic Dykes in the Inch (Aberdeenshire) Gabbro and its Aureole. *Proc. Geol. Ass., Lond.*, **62**, 237-47.
- . 1952. Metamorphism and Migmatization in the Ythan Valley, Aberdeenshire. *Trans. Edinb. geol. Soc.*, **15**, 265-79.
- . 1955. The Banff Nappe: an Interpretation of the Structure of the Dalradian Rocks of North-east Scotland. *Proc. Geol. Ass., Lond.*, **66**, 1-28.
- . 1956. The Dislocated South-western Margin of the Inch Igneous Mass, Aberdeenshire. *Proc. Geol. Ass., Lond.*, **67**, 73-86.
- & O. C. FARQUHAR. 1952. The Geology of the Arnage District (Aberdeenshire): a reinterpretation, *Quart. J. geol. Soc. Lond.*, **107**, 423-40.
- . 1956. The Buchan Anticline of the Banff Nappe of Dalradian rocks in North-east Scotland. *Quart. J. geol. Soc. Lond.*, **112**, 131-56.
- ROBERTSON, E. I. 1947. The Magnetism of Rocks. *Ph.D. Thesis, University of London*.
- ROCHE, A. 1950. Anomalies Magnétiques Accompagnent les Massifs de Pépérîtes de la Limagne d'Auvergne. *C.R. Acad. Sci., Paris*, **230**, 1603.

- SADASHIVAIAH, M. S. 1950. Olivine-bearing and other Basic Hornfelses around the Inch Igneous Mass, Aberdeenshire. *Geol. Mag.*, **87**, 121-30.
- . 1954a. The Form of the Eastern End of the Inch Igneous Mass, Aberdeenshire. *Geol. Mag.*, **91**, 137-43.
- . 1954b. The Granite-Diorite Complex of the Inch Igneous Mass, Aberdeenshire. *Geol. Mag.*, **91**, 286-92.
- SHACKLETON, R. M. 1948. Overturned Rhythmic Banding in the Huntly Gabbro of Aberdeenshire. *Geol. Mag.*, **85**, 358-60.
- . 1958. Downward-facing Structures of the Highland Border. *Quart. J. geol. Soc. Lond.*, **113** (for 1957), 361-92.
- STEWART, F. H. 1946. The Gabbroic Complex of Belhelvie in Aberdeenshire. *Quart. J. geol. Soc. Lond.*, **102**, 465-98.
- VINCENZ, S. A. 1952. Remanent magnetism of some Igneous Rocks of Great Britain and its Geophysical Significance. *Ph.D. Thesis, University of London*.
- WATSON, G. S. 1956. Analysis of Dispersion on a Sphere. *Geophysical Supplement, Monthly Notice, Royal Astronomical Society*, **7**, 153-9.
- WATT, W. R. 1914. The Geology of the Country around Huntly, Aberdeenshire. *Quart. J. geol. Soc. Lond.*, **70**, 266-93.
- WHITTLE, G. 1936. The Eastern End of the Inch Igneous Mass, Aberdeenshire. *Proc. Lpool geol. Soc.*, **17**, 64-95.

The Lower Greensand in the Hindhead Area of Surrey and Hampshire

by LEONARD KNOWLES and FRANK A. MIDDLEMISS

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ABSTRACT: The Lower Greensand between Witley, Surrey, and Woolmer Forest, Hampshire, has been mapped on the six-inch scale. Its general lithology and vertical and horizontal changes are described stratigraphically. Structurally the area is essentially that of the Hindhead Anticline, the form of which is described in detail. Large-scale superficial movements such as land-slipping and cambering have taken place, giving results difficult to separate from tectonic effects. The apparent right-angled change of strike of the Lower Greensand escarpment near Hindhead is ascribed to a combination of structural and denudational effects.

1. INTRODUCTION

THE AREA TO BE DESCRIBED covers some thirty-two square miles near the western end of the northern outcrop of the Lower Greensand in the Weald. The problem which originally stimulated the present work on the area was the explanation of the existence between Witley and Hindhead, Surrey, of one of the three great right-angled bends which affect the outcrop of the Hythe Beds, the other two of which are at Dorking and Bramley, south of Guildford. In each case the Hythe scarp is apparently deflected from an east-west to a north-south trend.

These phenomena have been little noticed in the published literature. Kirkaldy (1933b) assumed a monocline throwing to the west in each of the

three cases; Wooldridge (1950) suggested a possible tectonic dislocation at the Hindhead angle. Since no detailed map of this ground has been published it seemed evident to the authors that mapping on the six-inch scale was necessary, and this has now been done.

Detailed lithology and petrography of the sediments is not dealt with as it is intended to discuss these subjects in a future publication. Some results of mechanical analysis of the rocks of the area are given by Rogers & Richardson (1947) and of heavy mineral analysis by Wood (1957). Chapman (1894) discussed the microscopic contents of the Bargate Beds.

2. PREVIOUS WORK

The pioneer description of this area was that by Murchison in his first published paper (1826), in which he reconnoitred the whole western end of the Weald. His map, although remarkably accurate for a reconnaissance, is generalised in the Hindhead area itself. Fitton, in establishing the stratigraphy of the Lower Cretaceous throughout England (1836), mentioned Hindhead briefly and recognised the presence of the Hindhead Anticline.

The area was mapped on the one-inch scale by F. Drew for the Geological Survey and published as part of Sheet 8, SW., in 1862, Drew having moved into the district from that of Petersfield (Sheet 11, NE., published in 1858). No sheet memoir was issued and the area was described very briefly indeed in Topley's memoir on the geology of the Weald (1875). The extreme western fringe is included in the Geological Survey Sheet 300 (Alresford), resurveyed on the six-inch scale by C. E. Hawkins and published in 1898, but receives only scanty mention in Osborne White's memoir on the sheet (1910). Meanwhile Binstead Fowler had given a general description of the Hythe and Bargate Beds between Liss and Hindhead (1895).

The area was studied to some extent between the wars by members of the Weald Research Committee of the Geologists' Association. E. A. Turner worked on the eastern end for some years but never published any of his work except for a paragraph in the 1928 report of the committee (Wooldridge, 1928). J. F. Kirkaldy reconnoitred the area and referred to it in his paper on the Sandgate Beds (1933a). H. S. Rogers and J. A. Richardson mapped the northern part of the area on the six-inch scale between 1934 and 1936, but the work was never published and subsequently was lost except for the results of mechanical analysis (Rogers & Richardson, 1947), and an important paper on the formation of chert (Richardson, 1947). Kirkaldy and S. W. Wooldridge included the south-eastern part of the area in their notes on the country around Haslemere and Midhurst (Kirkaldy & Wooldridge, 1938), as did Wooldridge (1950) in his study of the country

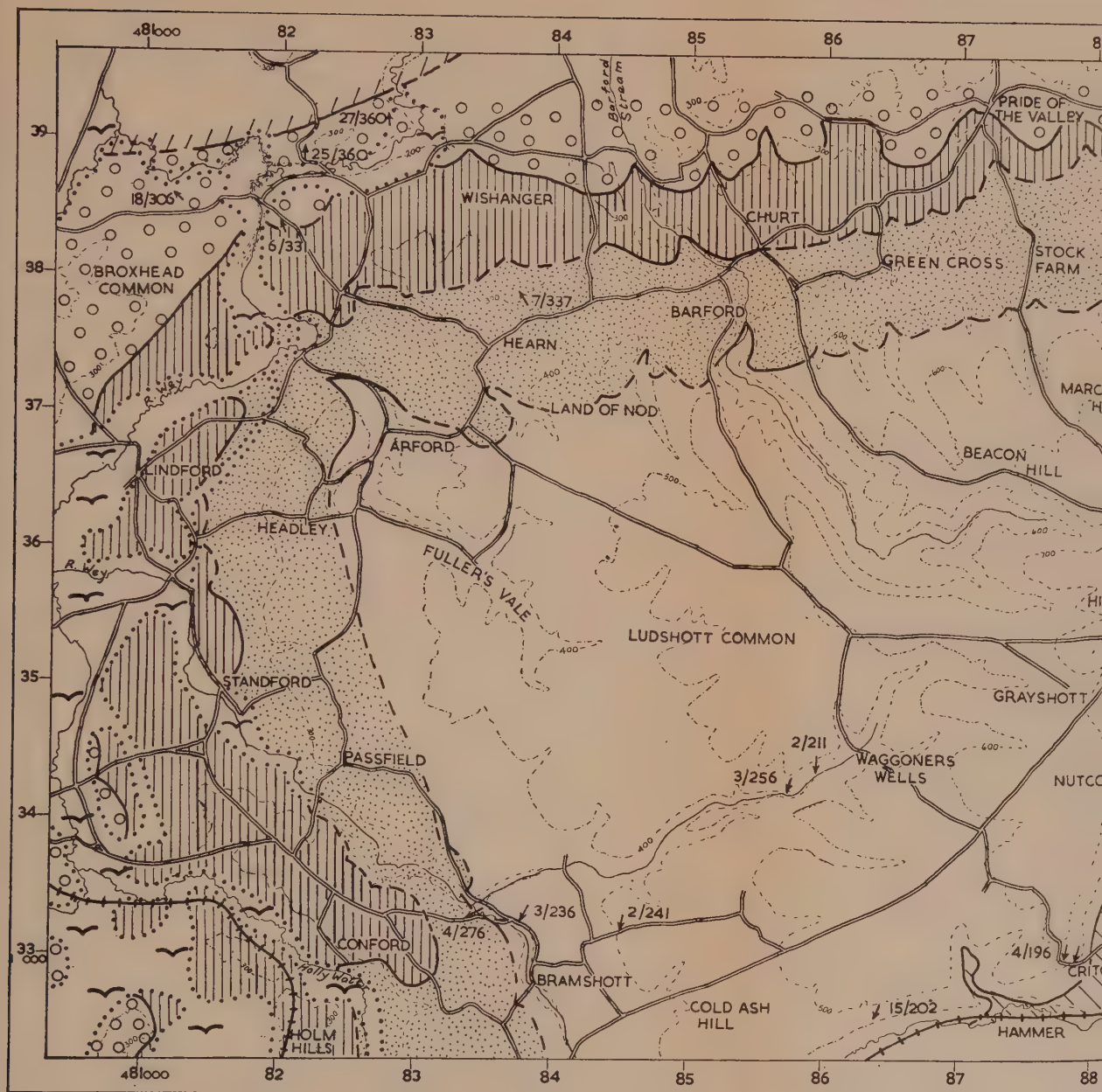
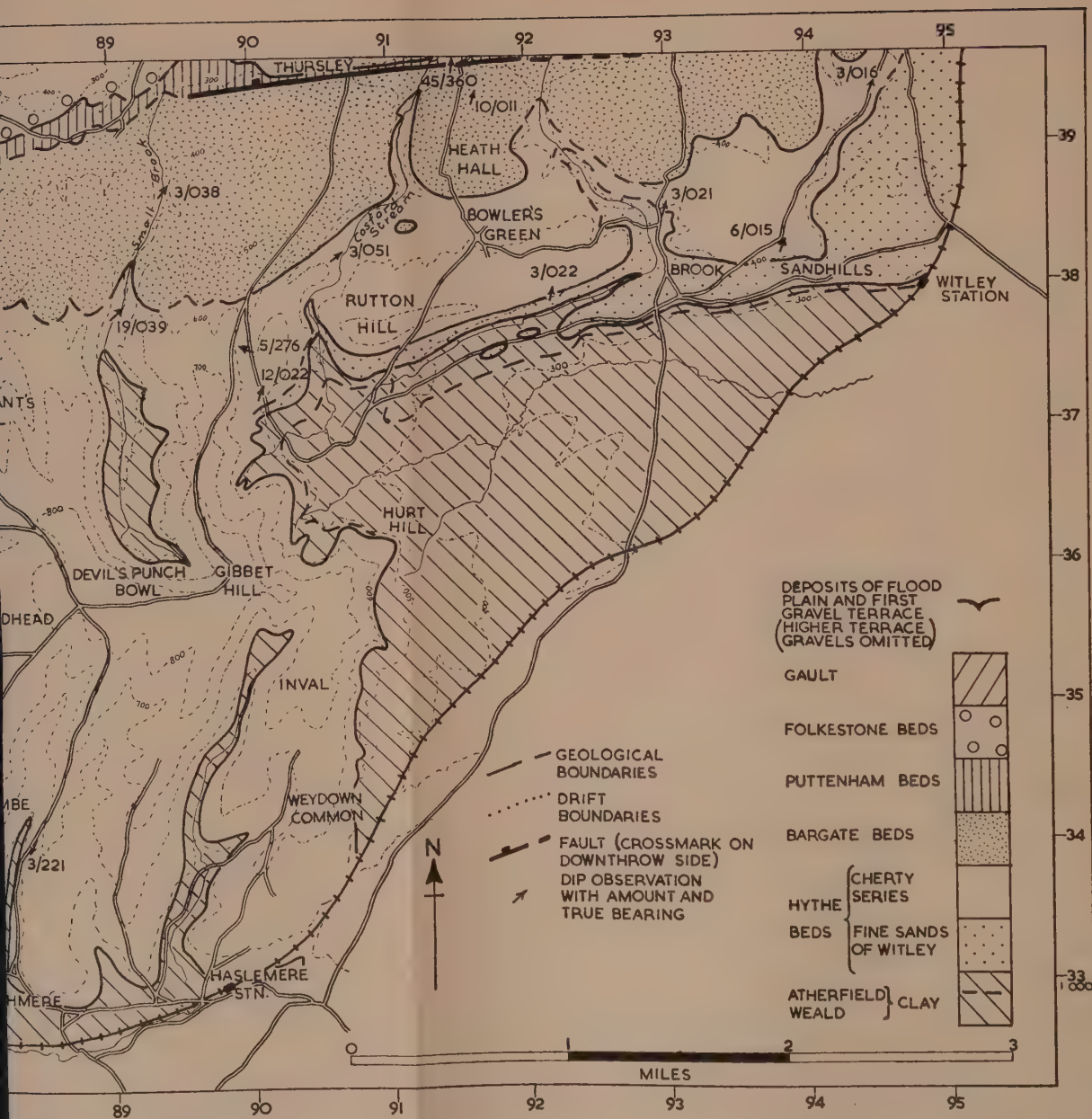


Fig. 1. Map of the Lower Greensand



around Fernhurst. The Geologists' Association has visited the area on rare occasions (Leighton, 1915; Turner, 1929 (no report published); Kirkaldy & Turner, 1930; Kirkaldy, 1948; Kirkaldy & Middlemiss, 1954).

The geomorphology of the Hindhead area has never received detailed attention. The drainage history of the Wey and Arun basins was dealt with authoritatively by H. Bury (1908, 1910); the Woolmer Forest area was discussed in general terms by D. L. Linton (1930); Wooldridge (1950) described the form of the Hythe scarp at Hindhead and Inval; Wooldridge & Linton (1955) refer several times to the area in the course of their synthesis of the denudation history of the Weald.

3. STRATIGRAPHY

The subdivisions of the Lower Greensand which have been recognised throughout the area are as follows:

FOLKESTONE BEDS		
PUTTENHAM BEDS (=Loamy Folkestone Beds of Dines & Edmunds, 1929)	}	SANDGATE BEDS
BARGATE BEDS		
HYTHE BEDS		
ATHERFIELD CLAY		

The estimates of thickness given are based partly upon well and boring records and partly upon measurement of true-scale sections drawn with the aid of stratum-contour maps for the base of each subdivision.

(a) Atherfield Clay

The lowest subdivision of the Lower Greensand is now poorly exposed in this area. Messrs. F. Milton & Sons' pit at Brook (931378)¹ shows the junction with the Hythe Beds, into which there is an imperceptible transition:

		ft.
HYTHE BEDS	3. Very fine silver sand	12+
ATHERFIELD CLAY	2. Iron-stained and variegated, very clayey silt	5
	1. Grey silty clay	5 exposed

The old brick-pit at Hammer (876325) shows a very similar transition:

HYTHE BEDS	4. Medium, rather clayey, variegated sands	
	3. Very fine sands	6
	2. Grey, variegated, clayey silt	9
ATHERFIELD CLAY	1. Silty clay at base	

A distinct line of water seepages occurs at the base of the grey silts.

Although there are at the present day no other exposures, a clay considerably more silty than the purer and more plastic Weald Clay beneath

¹ All National Grid references fall within 100 kilometre square 41 (SU) and 1 in. Ordnance Survey (6th Ed.) Sheet 169.

can be recognised by means of augering all round the base of the Hythe Bed escarpment. This is presumably Atherfield Clay and a line indicating approximately the position of its base has been marked on the map (Fig. 1). The base of the Atherfield Clay, with the underlying Weald Clay, crops out in the Haslemere Valley (Kirkaldy & Wooldridge, 1938), and probably also does so in the Devil's Punch Bowl, but any Weald Clay there is completely masked by slipped material.

The Atherfield Clay seems to thicken in a south-westerly direction. At least, mapping suggests a thickness of not more than twenty-five feet between Brook and Witley. Kirkaldy (1932) records twenty feet in the Hascombe country to the east, whereas Kirkaldy & Wooldridge (1938) found at least fifty-six feet in the Haslemere Valley and Drew records sixty feet in the Haslemere cutting (Topley, 1875, 114).

As to the inclusion of the silty clay in the Lower Greensand rather than the Wealden, the only fresh evidence during the present work has been one specimen of *Astarte* from the Haslemere Fire Station boring, but Kirkaldy & Wooldridge (1938 and references therein) record an abundant marine fauna, closely comparable with that of the Atherfield Clay on the Isle of Wight, from the Nutbourne, New Mills, Hammer & Brook brick-pits and the Haslemere railway cutting.

(b) Hythe Beds

The Hythe Beds, consisting essentially of sands and sandstones with chert, are fairly well exposed.

(i) *Between Witley and Blackhanger* (902375)

The beds here are clearly divisible into two parts, fine sands, and a cherty division.

The Fine Sands of Witley. These occupy the lower part of the succession and consist of fairly well-graded, yellow, buff or light-brown fine sands passing down into fine silty sand and clayey silt and so by transition into the Atherfield Clay. The base is exposed in the Brook brick-pit while the clean-washed, slightly ferruginous sands higher in the succession are seen in small exposures on Sandhills Common (942381).

This division is a local development, reaching its maximum thickness of well over 100 feet around Witley. Westwards the thickness decreases rapidly from 105 feet at Sandhills to about fifty feet south of Bowler's Green (916383), and about twenty-five feet at Blackhanger, the sand becoming, at the same time, more clayey in the lower part. South-westwards, around Gibbet Hill and Haslemere, the base of the Hythe Beds consists of fine sands but this division is very thin and not separately mappable. To the west of Hindhead the fine sand seems to be absent. This rapid thickening of the fine sands in an ENE. direction to a maximum

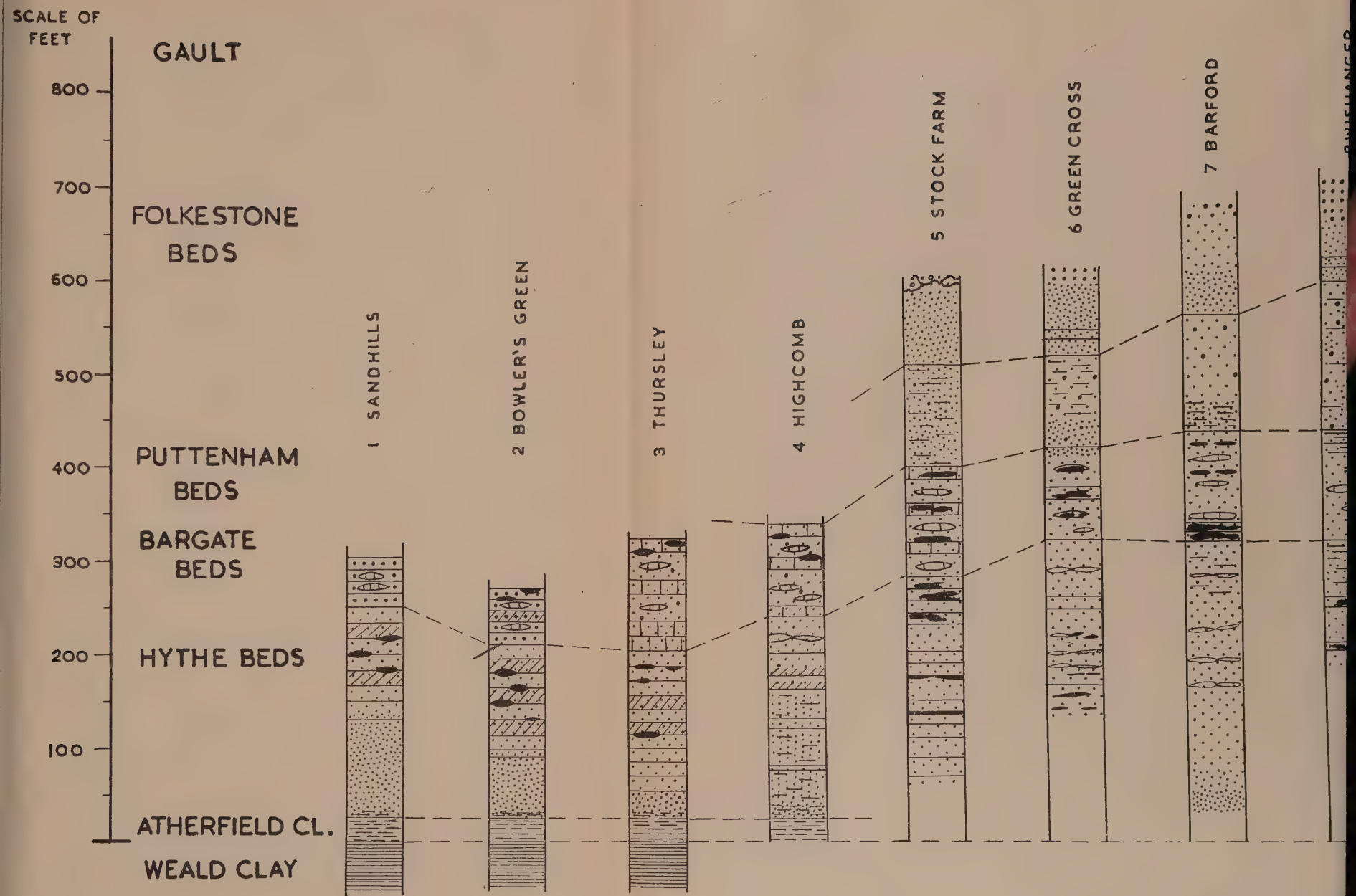
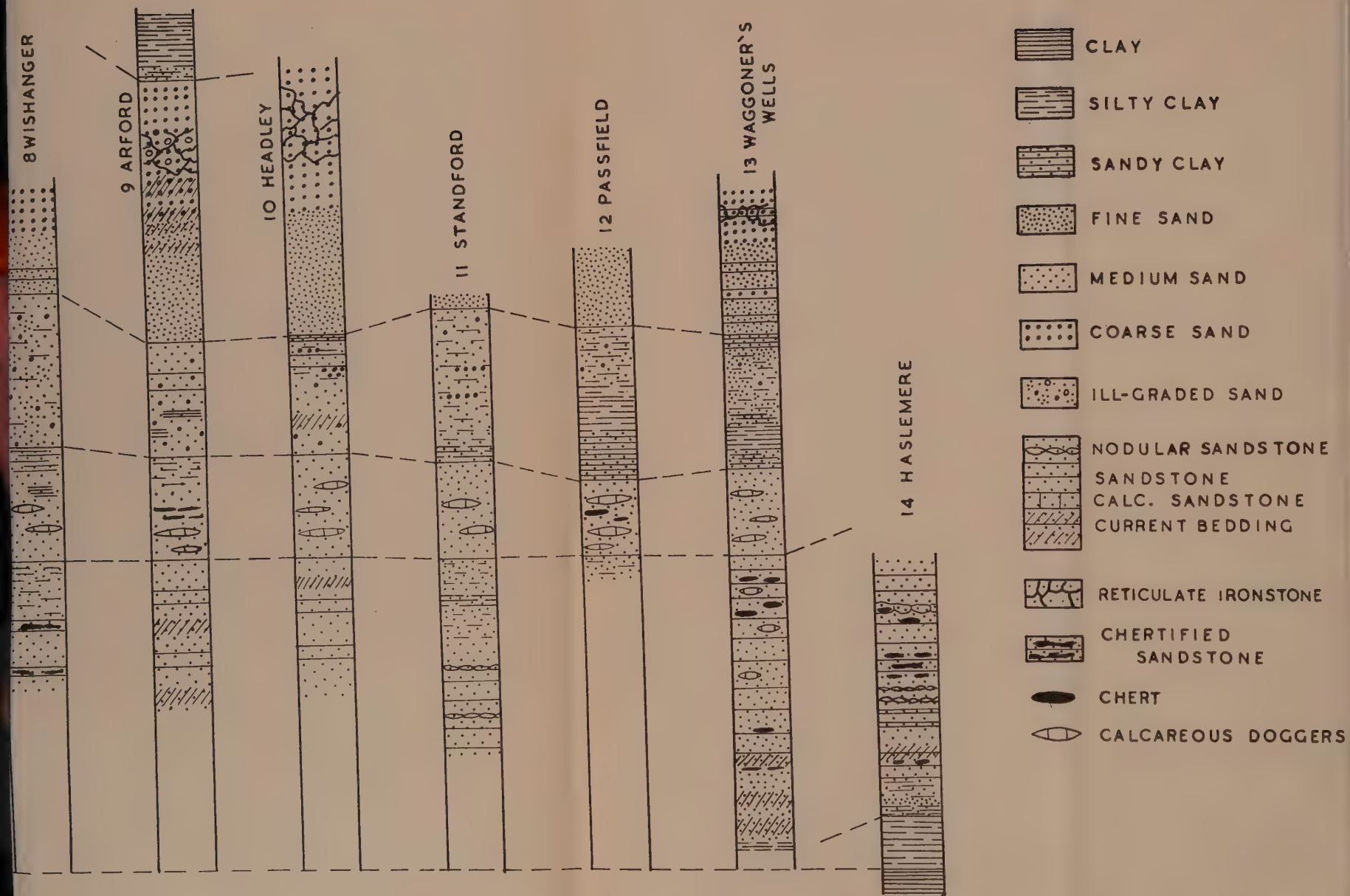


Fig. 2. Lateral variation in the Lower G



nd Witley can be clearly shown by superimposing the stratum cons of the base of the upper Hythe upon those of the base of the Hythe ; (Fig. 3).

ie Cherty Division. The beds immediately above the fine lower sands well exposed in the road section at 930386, north of Brook :

2. Coarser and more ill-graded glauconitic, spicular sand with abundant coloured constituents. Current-bedded (nine-inch foresets) in places. Irregular, nodular sandstone with lenticular dogger-like masses of cherty sandstone and chert and of highly ferruginous sandstone. 15 feet exposed.

1. Massive soft sandstone beds and sand. Medium-grained, with numerous small coloured constituents. Sandstone beds about three feet thick, full of irregular wisps of dark-grey silty clay. 36 feet.

he base of this section probably corresponds to the base of the cherty sion. Beds at much the same horizon are also well exposed in old pits lane sections. The highest beds can be seen just south of Cosford House 388), where they consist of medium sands, striped ferruginous and ; with soft, non-calcareous sandstone and some cherty sandstone.

he cherty division in this part of the area varies considerably in thick- ;, tending to thin as the fine sands thicken. North of Brook there are bably about twenty-six feet of cherty division unexposed above the ion described above, making some seventy-seven in all. Near Black- ger there are about 120 feet of beds between the fine sands and the gate Beds and the original thickness was probably at least of this order ng the line of the Brook-Sandhills escarpment, but this division thins thwards and mapping near the upper lake in Witley Park (922390) icates only about fifty to seventy feet of cherty division.

The Gibbet Hill and Haslemere Area

n this area exposures are numerous enough to enable a composite ion of the whole of the Hythe Beds present to be built up, although the xremost beds have been removed by erosion.

The basal beds are shown in the Hammer brick-pit (p. 207) and the bank the opposite (north) side of the River Wey at 874327. The best section in the Beds in the whole area at present (May, 1955) is at 878329, where the d from Critchmere to Woolmer Hill has been widened, resulting in a ; road section :

feet

5. Abundant chert bands up to six inches thick and cherty sand- stone. Chert blocky and lenticular. Sands medium-grained, fairly well-graded. All of ruddy, ferruginous colour. Glauconite and sponge spicules present exposed 31

- | | | | | | | |
|--|-----|-----|-----|-----|-----|------------|
| 4. Lines of rubbly, irregularly nodular, slightly cherty spicular sandstone, about four inches thick and nine to twelve inches apart, in sand as of group above but less ferruginous. Thin ferruginous seams are present. Strongly developed chert of group 5 absent | ... | ... | ... | ... | ... | exposed 19 |
| 3. Yellow sand with much glauconite and haematite. Upper part has prominent and persistent sandstone bands; stone in lower part more rubbly and impersistent | ... | ... | ... | ... | ... | exposed 52 |
| 2. In upper part massive soft, strongly current-bedded sandstone. Fairly well-graded, with much haematite and some clayey wisps. Includes lenses, a few feet long by a few inches thick, of strongly cherty sandstone. The lower fifteen feet are rather thinner bedded and more rubbly, with loose sand | ... | ... | ... | ... | ... | 38 |
| 1. Sands with very little stone, becoming clayey near base. Sand finer than in higher groups | ... | ... | ... | ... | ... | 28 |

The base is not exposed but must be immediately above the Royal Oak Inn, so that the twenty-eight feet of the lowest group contains the beds seen at Hammer. The base of group 4 and the top of group 3 are not exposed owing to faulting, which brings down group 5 between those groups, but the thickness of the missing beds is probably small. In the middle of group 2, on the north side of the road, is a small intra-formational fold or slump structure.

This accounts for some 168 feet of the probable maximum thickness of 270 feet surviving erosion in this neighbourhood. The remaining 100 feet can be seen in small exposures around Gibbet Hill and consists of medium sand with both massive and nodular non-cherty sandstone, some chert and cherty sandstone. Fitton (1836) saw cherts exposed along the Portsmouth Road at Hindhead.

It is to be noted that the main development of chert occurs here in about the middle of the Hythe Beds (group 5) and it is this which is best exposed between Hindhead and Haslemere. Massive sandstone similar to that of group 2 is exposed on the main road between Critchmere and Nutcombe and was at one time quarried on Weydown Common (903345).

(iii) *The Small Brook Valley*

The deep gorge of the Small Brook, which rises in the Devil's Punch Bowl and drains Highcomb Bottom, provides a good series of exposures through both Hythe and Bargate Beds. In Highcomb Bottom itself augering provides some evidence of the presence of fine silty sand at the base of the Hythe Beds, but there is probably very little of it.

Entering the gorge to the north of the Keeper's Cottage in Highcomb Bottom the stream first exposes clayey fine to medium sand, with some soft sandstone, of which there is apparently about 120 feet. In the southern part of Vanhurst Copse, where the gorge is particularly deeply incised, the exposures are of soft massive glauconitic sandstone and medium to fairly

coarse ill-graded sands. At the top are highly glauconitic sands with the glauconite concentrated into closely spaced, irregular quarter-inch thick seams, the sand between the seams being fairly well graded and clean washed; small sandstone nodules occur, with the glauconite seams continuing uninterruptedly through them.

The most unexpected feature of the section is the absence of chert and cherty sandstone, which is present in force in the Hythe Beds of the higher ground immediately east and west of the gorge, as on the track from Highcomb to Thursley at 889376 and south of Upper Highfield at 895378, 130 yards west and 500 yards east of the Small Brook respectively.

(iv) *West of Hindhead*

In the western part of the area, that is to say west of the Small Brook gorge, the Devil's Punch Bowl and the Portsmouth Road, the beds are very variable and it has not been found possible to trace any continuous horizons.

In the block of country comprising the northern slopes of Hindhead, between the Small Brook and the Barford stream, the beds consist of medium sand with soft sandstones and irregular, nodular sandstone and contain a considerable amount of chert, which was at one time well exposed in the excavation dug for the reservoir on the Tilford road at 875374 (Humphries, 1953). In the Hyde Hill and Marchant's Hill area, north of Beacon Hill, strongly cherty sandstone and chert is particularly well developed at the very top of the Hythe; west of the Tilford road, however, this development dies out.

The deep valley of the Barford stream, or Whitmoor Bottom, cuts through practically the whole thickness of the Hythe Beds, which are shown in several small scattered exposures. Although there does not seem to be any Atherfield Clay exposed in the bottom of the valley, augering near the stream in the middle part of the valley, near point 859367, found light greyish-brown clayey silt which cannot be far above the base of the Hythe Beds. This grades up into buff silty fine sand and then into ferruginous fine to medium sands exposed in the upper part of the valley near Stream Farm (864360). The higher 250 feet or so consist of ferruginous, ill-graded, rather clayey medium sand with nodular sandstone. As in the Small Brook gorge, chert seems not to be present in Whitmoor Bottom.

The Hythe Beds in the north-west corner of their outcrop, between Whitmoor Bottom and Arford, contain very little chert but consist of medium, fairly ill-graded, glauconitic sand, locally current-bedded, with soft massive sandstone, while the highest beds, shown in small exposures just south of Land of Nod, are fine to medium, rather clayey, glauconitic sands, similar to those of Whitmoor Bottom.

In the neighbourhood of Arford there are several good exposures, e.g. at

838368 at the west end of Headley Common. The lane bank at 82803675 shows well-graded, quite clean-washed, glauconitic, fine medium sand which is strongly current-bedded, with foresets about two and a half feet in amplitude, glauconitic seams running parallel to the foreset beds. The current-bedded sand here is a lens, probably a channel infilling, set in non-current-bedded sands which contain irregular, rubbly non-cherty sandstone bands and small, irregular nodules of cherty sandstone, containing moulds of sponge spicules. The old sand-pit on the side of Curtis' Hill, immediately above the road junction at 826366, shows a section rather similar to the last but much larger. Current-bedding is extremely well developed with foresets two and a half to three feet in height.

In Fuller's Vale there are several old overgrown pits which now show little, but further up the vale, at 836358, a quarry belonging to Messrs. Fyfield & North provides a good exposure of some twenty feet, mostly of sandstone. The sandstone occurs in massive, rough, nobbly beds, some six feet thick, and is non-cherty, fine to medium grained. Among the more massive beds occur irregular bands, four to five inches thick, which show distinct one-eighth inch layers of glassy chert. There is more soft sand towards the top of the pit, where it is roughly banded, ferruginous and pale, and contains very irregular seams and doggers of sandstone of similar type to the more massive stone below. There is no sign of current-bedding or of calcareous material.

Augering in Hilland Woods and around Upper Passfield provides evidence of the nature of the upper eighty feet or so of the Hythe Beds in this area. Above the beds exposed in Fyfield & North's quarry come well-graded, but silty, sands, followed upwards by stiff, plastic, very clayey sand, variegated rust and light green in colour, found in the eastern part of Hilland Woods (833357) and probably local and lenticular in occurrence. Above this come some thirty feet of silty, ill-graded, fine to medium sands, probably extending to the top of the Hythe Beds, although the junction with the Bargate Beds is hidden beneath the gravels of the 300-foot terrace.

In the south-western part of the area there is a fine series of exposures around Waggoner's Wells and Bramshott. Although the Atherfield Clay is not exposed in the Waggoner's Wells Valley, the head of the uppermost lake (863345) cannot be very far above the base of the Hythe, since augering here found grey and buff clayey silt. Above this come about eighty feet of banded sands and massive and rubbly sandstones with little chert but with locally well-developed current-bedding. These beds are seen in several old pits and small exposures in the valley, especially the old sand-pit at 875342, by the third lake down, which shows current-bedded channel infillings and 'ferruginous lenses' (p. 214), and the exposure at 849339, by the boat-house of the lowest lake, which shows massive, non-cherty sandstone

beds, four feet six inches thick, with well-developed 'ovoid ferruginous cavities' (p. 214).

The upper part of the Hythe Beds consists in this part of the area of some 180 feet of fine to medium sand with soft massive sandstone, calcareous doggers and chert, calcareous sandstone in the Hythe being apparently confined, at the present day, to this south-west corner of the area. These beds are well exposed around Bramshott. Rectory Lane (845332) shows rough, massive beds, four feet thick, of soft, medium, fairly ill-graded sandstone, neither cherty nor calcareous, very similar to those of Fyfield & North's pit and of Waggoner's Wells. Associated with the massive sandstones are thinner (four inches), more irregular and prominent bands which are cherty, although not noticeably spicular, occasional large ovoid doggers, up to about five feet in length, which are of fine- to medium-grained strongly calcareous sandstone, and fine to medium sand. The doggers are the only site of calcareous matter, the loose sand being quite non-calcareous. There are also large numbers of both 'ferruginous lenses' and 'ovoid ferruginous cavities'.

Woolmer Lodge Lane contains a good exposure at 841336, just south of the bridge, showing nearly thirty feet of the beds. Thin impersistent sandstones and ovoid calcareous doggers, up to six feet long by one and a half feet thick, occur in banded sand. About twenty feet above the lowest point exposed is a band one foot thick of very strongly cherty sandstone, solid chert in parts, which appears continuous as far as can be seen. Beneath this band is an impersistent two inch seam of very deep-ruddy coloured ferruginous sand.

Similar beds are exposed in other lanes around Bramshott Church. On the east side of the road at 83703325, opposite Bramshott Mill, an exposure shows irregularly banded ferruginous and pale-grey sand with several large doggers, up to two feet long by one foot thick, of hard calcareous sandstone, associated with which are 'ferruginous sand lenses', and also beds, some nine inches thick, of soft non-calcareous and non-cherty sandstone. This exposure is not more than about twenty feet below the top of the Hythe Beds. At 849327, beside the Portsmouth Road at Cold Ash Hill, is an old pit showing a good face some twelve feet high with some irregular development along the bedding planes of fairly hard but non-calcareous and non-cherty sandstone and also, in the centre of the face, a very good line of 'ovoid ferruginous lenses'.

(v) *Thickness and General Characters of the Hythe Beds*

In the northern part of the area the Hythe Beds as a whole become fairly rapidly thinner from south to north. A well at Milhanger, Thursley (913397),¹ apparently penetrated only 228 feet of combined Bargate and

¹ All well records are taken from Geological Survey Wartime Water Supply Pamphlet No. 15, Part 5.

Hythe Beds before reaching Atherfield Clay. At Rodborough Hill to the north-east (941418) the equivalent figure was 237 feet. At the Tilford Road pumping station, Thursley (873409), $240\frac{1}{2}$ feet of Bargate and Hythe Beds were passed through without reaching the base, although it seems likely that the Atherfield Clay must have been almost reached; here, however, the detailed record enables this figure to be divided between the Bargate Beds and the Hythe Beds, the former having apparently a thickness of $62\frac{1}{2}$ feet and the latter $178 +$ feet. Thus at Milhanger the Hythe Beds must have a thickness of the order of 160–170 feet. Southwards from Blackhanger to Haslemere the topmost beds have everywhere been removed by erosion but it is evident that southward thickening here overtakes the effect of the attenuation of the fine lower sands since a well at Hindhead cross-roads gave a record of $295\frac{1}{2}$ feet of Hythe with neither top nor bottom present.

To the west of Highcomb Bottom northward thinning remains a dominant character of the Hythe Beds. The Small Brook gorge traverses the whole thickness of the Hythe Beds, which does not seem to be much more than 150 feet, whereas the $295\frac{1}{2}$ feet of the Hindhead cross-roads well is only just over a mile to the south. Westwards, along the southern boundary of the Bargate Beds outcrop, the probable actual thickness of the Hythe Beds increases steadily, from 150 feet at Bedford Farm and the Small Brook gorge to 210 feet near Marchant's Hill, 275 feet south of Green Cross (864381) and 300 feet at Barford. South-west of here any estimate of the altitude of the base of the Hythe Beds becomes too unreliable except in the Waggoner's Wells Valley where, near Cooper's Bridge (835334), it is possible to estimate the total thickness at about 300 feet.

An interesting lithological feature of the Hythe Beds is the presence of 'ovoid ferruginous cavities' and 'ferruginous sand lenses', already referred to. The former are ovoid cavities in sandstone beds, usually one to three feet in length and up to one foot in height and lined with deeply ferruginous sand, sometimes arranged in lines parallel to the bedding. The latter are ovoid lenticles of deeply ferruginous sand, of the same size and shape as the 'ovoid cavities' and showing the same arrangement, but set in unconsolidated sands. It is suggested that these represent stages in the destruction by decalcification of small calcareous doggers such as are found in the Hythe Beds at Bramshott. As the dogger becomes decalcified it turns into an ovoid mass of loose highly ferruginous sand with the liberation of ferric iron which so often accompanies decalcification. In unconsolidated sands this remains as a 'ferruginous lens' but in a sandstone the difference in resistance to weathering between the decalcified lens and the surrounding stone results in the sand being cleared out to leave a sand-lined 'ovoid ferruginous cavity'. The link in this sequence is supplied by some exposures near Bramshott, especially in the roadside just west of the church (840329),

where ferruginous lenses can be seen which still retain in the centre a remnant of highly calcareous stone, exactly comparable with that of the fully calcareous doggers of the same neighbourhood; the decalcified material is typical Hythe silty sand but is unusually ferruginous. If this suggestion is correct it implies that calcareous doggers were formerly much more widespread in the Hythe Beds than they now are, since these phenomena are not confined to the Bramshott district (e.g. Rectory Lane, Cold Ash Hill and Bramshott Mill) but have been found occasionally throughout the area, e.g. at Waggoner's Wells, in the Small Brook gorge, near Rutton Hill and at Brook. Neither are they confined to the Hythe Beds but have been observed in the Bargate Beds near Headley and Bramshott and even in the Puttenham Beds at Holm Hills (821326).

Current-bedding is not common in the Hythe Beds but has been seen at several places. Wherever seen in the north-eastern sector of the area it is on a small scale, the foreset beds having a height of only a few inches (the maximum being two feet at 945394, near Witley), but in the south and west, around Haslemere, Waggoner's Wells and Arford, there are occurrences of foresets several feet in height, as already described, reaching a maximum in the Critchmere section (p. 210) with foresets eight feet high. The comparative rarity of current-bedding in the Hythe and its frequent rather abrupt association with completely level-bedded deposits suggest that where it occurs it should be regarded as marking infillings of current-eroded channels. On a small scale this can be seen particularly clearly at 82803675, Arford (p. 212), and 857342, Waggoner's Wells (p. 212), and it probably applies to the larger-scale occurrences. The foresets, so far as can be seen in unconsolidated sands, appear to be always inclined approximately from the north-west.

Humphries (1953), after a study of the Hythe Beds to the south of the area under consideration, concluded that they were deposited in very shallow water, perhaps tidal, but far from shore, where quiet conditions prevailed; the beds in the Hindhead area seem to suggest that these quiet conditions were from time to time, during the period of deposition, disturbed by strong currents acting along a zone from Arford in the north-west through Waggoner's Wells to Haslemere in the south-east.

(c) Bargate Beds

The Bargate Beds are clearly distinct from the Hythe Beds towards the eastern limits of the area but the two groups become increasingly difficult to separate towards the south-west.

(i) *Between Witley and Thursley*

In the area between Witley and Cosford the Bargate Beds consist of coarse, ill-graded sandstone and sand, usually current-bedded, the stone

occurring entirely in the form of highly calcareous doggers except for some spicular sandy chert occurring mainly, but not exclusively, near the top (the Top Chert of Kirkaldy, 1933a). Exposures are poor, the only ones worth noting being in the lanes leading north from Heath Hall (917387) and Bowler's Green. Small exposures in the lanes between Thursley and Blackhanger show the beds already beginning to change slightly in character in that the sand and sandstone is slightly less coarse. Nowhere in the area between Witley and Thursley is the Hythe-Bargate junction exposed. It seems unlikely that there is any actual break between these formations here but the differences between them are amply sufficient for mapping by auger, soil change and, east of Witley Park, by a feature.

(ii) *The Small Brook Gorge*

Here is found a series of exposures which make it clear that there is a transition from the Hythe Beds to the Bargate Beds, and no break, and also that westward lateral change in the Bargates has proceeded so far as to make part, at least, of these beds difficult to distinguish from the Hythe. This change consists mainly of decrease in grain size, together with the appearance of glassy, non-spicular cherty sandstone resembling a type seen in the Hythe Beds but differing from the typically highly spicular chert of the Bargate Beds further east. Thus the Bargate Beds in the Small Brook gorge consist essentially of ill-graded, glauconitic medium sand with numerous calcareous sandstone doggers and cherty sandstone.

In Vanhurst Copse, about twenty feet above the sand and nodular sandstone with extremely glauconitic seams which has been taken as the uppermost part of the Hythe, calcareous doggers occur on both sides of the stream. A hundred yards further north, and some thirty feet above the stream, calcareous doggers occur in very ill-graded, distinctly silty ferruginous sand which contains large subangular quartz grains, larger than those normally seen in the Hythe sands, and is full of coloured constituents, especially glauconite and haematite. In the next 150 yards to the north are several exposures showing fine-grained calcareous sandstone doggers in sand similar to that just described and after that are found large doggers of typical coarse, ill-graded calcareous stone, unmistakably Bargate, although the associated sand is still of the rather indeterminate medium to fine ill-graded type seen in the exposures just to the south. It will be seen that over a distance of 250 yards and a stratigraphical thickness of about forty feet there are beds which are not convincingly separable from the Hythe or from the Bargate but which contain calcareous doggers. The line, which has been drawn below the lowest calcareous doggers, is necessarily arbitrary since there is little doubt that the absence of calcite from the Hythe Beds is to a large extent a secondary feature and calcareous doggers survive in those beds near Bramshott, as also further to the south-west near Sheet

(Humphries, 1953), but it is considered that (a) there is no evidence of the present existence of calcareous doggers in the Hythe Beds between Hindhead and Witley, (b) the line chosen divides a series in which the stone is soft non-calcareous and non-cherty sandstone, typical of the Hythe, from one in which the stone is all either calcareous or cherty.

Beds a little higher in the Bargate succession are shown in a number of good exposures near the footbridge (894386) between Ridgeway Farm (called Hindhead Nursery on the six-inch map) and Upper Highfield. Large doggers, some one and a half feet thick, are exposed along the steeply ascending paths east and west of the footbridge; the sand varies, some being quite coarse while some is of the medium, indeterminate type seen just to the south. Among the doggers are occasional bands, four inches thick, of irregular cherty sandstone of glassy, non-spicular type. At the footbridge itself and also by the stream 150 yards further north a different type of rock is exposed, a coarse, ill-graded, calcareous fairly soft sandstone, with much glauconite and lydite, containing many shell fragments, Polyzoa and sponge spicules. Eventually, after another 150 yards northwards, the streamside exposures show that both stone and sand are of a coarser type reminiscent of the Bargate exposures a little further east, near Cosford and Thursley. It is likely that these south to north changes reflect not so much passage across different stratigraphical levels as a general south-west to north-east change in lithological character.

(iii) *West of the Small Brook*

From the Small Brook gorge to Churt the essential characters of the beds undergo little change but this area contains the maximum development of chert in the Bargate Beds. The principal exposure here is the large quarry behind Stock Farm, Churt (877382), described by Richardson (1947). At present this shows some fifty feet of the beds with neither base nor top exposed. The sand is medium, ill-graded, generally silvery but with much glauconite and with ochrous streaks associated with the chert, and is strongly and irregularly current-bedded. The cherty rock occurs as irregular, variably sized doggers in the upper twenty feet of the face, where no calcareous stone occurs. The lower part of the face consists also of large doggers in sand but the doggers in this case are mainly calcareous, some undergoing silicification. Another exposure described by Richardson (1947) was the Green Cross quarry, Churt (865382), where there is comparatively little to be seen now. Richardson's record of *Parahoplites* aff. *nutfieldensis* from this pit (ibid., p. 171) equates the Bargate Beds of this area stratigraphically with the Sandgate Beds of East Surrey and Kent.

Apart from these two quarries there are numerous small exposures in this tract, mostly in lane sides and bottoms. The great majority of these exposures are non-calcareous and show spicular cherty sandstone or sandy

chert in fine to medium sands, the nature of the sands varying considerably in one exposure from well-graded and clean-washed to ill-graded, silty or distinctly clayey. The few exposures which show calcareous doggers are all to the north of the latitude of Stock Farm quarry, so that non-calcareous, cherty material is always found at the outcrop in contact with Hythe Beds. For this reason the Hythe-Bargate boundary is particularly difficult to map here, the non-calcareous Bargate sand not being sufficiently different from the Hythe sand for augering to be of much assistance; reliance has to be placed mainly on the nature of the outcropping stone and on surface features such as vegetation and land-use; birch, bracken, conifers, ling and, in particular, heather are associated mainly with the Hythe Beds, chestnut coppice, orchards and arable cultivation generally almost confined to the Bargate outcrop. Heather is a good guide, being almost entirely absent from the Bargate outcrop except where the latter is covered by drift.

Evidence of a small lenticular development of plastic silty clay about the middle of the Bargate Beds is provided by augering in the immediate vicinity of point 868382, east of Green Cross.

In the Barford Valley the junction with the Hythe Beds can be placed accurately on the path leading down from the west to the footbridge at the lower end of Barford Pond (853375), where the medium sand and irregular non-cherty sandstone of the Hythe is overlain by somewhat coarser sand with more abundant large quartz grains and coloured constituents. Large calcareous doggers, some fifteen feet long by one or one and a half feet thick, set in ashy-coloured calcareous fine to medium and non-calcareous sand, are exposed in old quarries on the east side of the valley by the mill pond (854380) and in the lane and the stream bank immediately west of Barford Bridge (853381).

Between Barford and Arford the Bargate Beds consist of medium, ill-graded sand, clayey locally, with calcareous doggers, except that the lane leading from Hearn Cottage to Saunder's Green exposes a section some 200 yards long (833376) which is peculiar in containing no stone; it consists of soft sand, completely non-calcareous and very varied, in places loamy and variegated orange and greenish, in others clean-washed and fairly well-graded fine sand. The boundary between the Hythe and Bargate Beds is again difficult to trace accurately in this tract but land-use is a considerable help, the contrast in fertility being particularly noticeable on the Land of Nod estate (842371). Augering to the north of the Churt-Headley road shows that the highest twenty feet or so of the Bargate consists here of very clayey medium sand.

In the immediate neighbourhood of Arford and Headley there are several small exposures of the beds. Augering near Bayfield's Farm (823375) shows that the very clayey greenish-grey medium sand horizon at the top continues as far west as this. Below this the beds consist of medium,

glauconitic sand, fairly ill-graded to fairly well-graded, with calcareous doggers and cherty sandstone; it is not true that the calcareous development is absent in this district as suggested by Richardson (1947, 164).

South of Headley a good deal of the Bargate outcrop is beneath the gravel of the 300-foot terrace of the Wey and there are few exposures except in the old quarries around Passfield. Augering is possible in the valleys cut into the 300-foot platform and there are a few lane exposures. The old Passfield quarries (Kirkaldy, 1933a) are all disused and much overgrown and only small exposures remain. They show large doggers, some twenty feet long by two feet thick, of fine medium calcareous sandstone in light-coloured calcareous sands; cherty stone also occurs. The samples given by augering in this part of the area are of fairly well-graded, homogeneous, non-calcareous, fine to medium, soft glauconitic sand without clay fraction.

The southernmost exposure in the area is at 834333, north-west of Bramshott, which shows well-graded fine medium sand without current-bedding but with small (twelve by seven inches) calcareous doggers and 'ferruginous lenses'. The doggers vary amongst themselves, some being of fairly coarse sandstone. At this south-western end of the area mapped the Bargate and Hythe Beds resemble each other closely and anyone approaching the north-west Weald from this direction, as the original surveyors of the Geological Survey did, would naturally regard the Bargates as merely a rather more calcareous development of the upper part of the Hythe. Certainly the sand of this exposure is indistinguishable under the lens from that of the neighbouring exposure of Hythe near Bramshott Mill (83703325); the calcareous doggers in the Hythe of Bramshott are likewise indistinguishable from the finer ones of the Bargates, such as those of the Passfield quarries (although the coarser Bargate doggers, which also occur in this south-western area, are a type not found in the Hythe). The most significant difference that remains is that in the Bargate Beds all the sandstone is either in the form of calcareous doggers or is cherty, whereas in the Hythe soft massive sandstone occurs which is neither calcareous nor cherty, in addition to calcareous doggers and chert material. This could almost stand as a diagnosis of the two formations for the whole area from Witley to Bramshott except that a little non-calcareous non-cherty sandstone has been found in the Bargates around Headley.

(iv) *Thickness and General Characters of the Bargate Beds*

To the east of Witley, Kirkaldy (1932) estimated a thickness of sixty feet for these beds. They increase in thickness westwards, about 120 feet being present near Blackhanger, with the top eroded. In the Small Brook gorge there is probably a comparable thickness but northward thinning affects these beds as it does the Hythe and there is probably not more than ninety feet beneath the Puttenham Beds at the northern end of the gorge.

West of the Small Brook the thickness varies between 100 and 120 feet within the area mapped. That northward thinning continues to be important is shown by the contrast between these figures and the sixty-two and a half feet given by the Tilford Road well. South of Standford the beds appear to thin slightly again to between eighty and one hundred feet.

The dominant feature in the sedimentation of the Bargate Beds is the reduction in general grain size from north-east to south-west. Current-bedding is common in the beds east of the Small Brook but less so to the west. There is no reason to modify the palaeogeographic picture drawn by Kirkaldy (1933a, 1939).

(d) Puttenham Beds

The Puttenham Bed outcrop enters the area mapped at French Hill, Thursley, to the north-east of which is a fine exposure at Milford Cemetery pit (940416) (Kirkaldy & Middlemiss, 1954).

(i) *French Hill to Churt*

At French Hill itself (915396) the exposure shows coarse medium, highly limonitic and glauconitic loamy sand, full of rounded shiny limonite grains, with well-developed reticulate ironstone, overlain by seventeen feet of very ill-graded, silty, glauconitic loams with fine to medium sand fraction. These latter become more clayey towards the top and at the top is a sandy and silty light-grey clay underlying the Folkestone Beds.

Westwards from here the outcrop forms a belt of low and often damp ground and there are very few exposures. Augering and a few small roadside exposures, however, show that the beds are very different in this tract from those further east, as already noted by Kirkaldy (1933a), and consist of fine to medium silty and clayey ill-graded sand. As Churt is approached a coarser fraction begins to be found again, the first sign being the reappearance in the upper two-thirds of the beds between the Pride of the Valley Inn (872393) and Green Cross of the characteristic shiny pellets of limonite. Around Churt itself augering shows that most of the beds consist of coarse ill-graded sand with many large rounded grains of limonite.

(ii) *Churt to Headley*

The chief characteristic of the Puttenham Beds in this tract is the very ill-graded nature of the sands. Large shiny limonite pellets are nearly everywhere abundant.

In the area around Wishanger Ponds there are no exposures and mapping has to be done by augering and soil but the road running from Headley to Huntingford Bridge has several exposures in successive levels of the beds. The entrance drive to Prospect Hill Farm (824377) shows very ill-graded medium to coarse sand with great abundance of large rounded

shiny fragments of limonite; this is about twenty feet above the clayey top of the Bargate Beds. A small entrance drive at 826380 exposes a section about five feet high, the lower two feet of which is composed of very coarse ill-graded sand extremely rich in shiny limonite grains and has abundant light-coloured worm-borings; the upper three feet is similar in general character but finer, with thin, irregular, greenish clay seams. Just to the north along the lane are similar exposures, some showing the thin clay seams better. Further north still, about 826384, a small lane-side exposure shows medium to coarse ill-graded soft sandstone with great abundance of the characteristic limonite grains.

In Headley Park, on the west bank of the Wey round about 816380, are exposures of the highest part of the beds. They consist essentially of very ill-graded, silty and clayey, variegated ochrous and greyish medium sand, which contains seams of very much coarser ill-graded sand, full of limonite pellets, and irregular seams of coarse, very strongly ferruginous soft sandstone. Further south along the west bank of the Wey, at 814372, are small exposures which illustrate most of the lithological types found in the Puttenham Beds. They show firm faces of sand, banded ferruginous and light-coloured, consisting of clayey, ill-graded sand, light in colour, with lenticles, some of which are fossiliferous, of highly ferruginous soft sandstone full of large oval polished limonite grains. Some of the lighter-coloured sands, however, are clean-washed and full of light-coloured worm-borings. In places current-bedding occurs (foresets one and a half feet high), the current-bedded sand being clean-washed but full of limonite grains and much resembling that of Milford Cemetery pit, although finer. The fossils include *Parahoplites* sp.

(iii) South of Headley

In this tract the Puttenham Beds gradually change their character considerably. Proceeding southwards from Headley Park the first change is the incoming of a thin bed of sandy clay right at the top, as in a similar position at French Hill. The most northerly point at which this has been found by augering is 811376, on the bridle path from Headley to Sleaford, from which it can be traced south-westwards along the edge of Broxhead Common. Whether this clay forms a continuous horizon is difficult to say, since the Puttenham-Folkestone boundary is mostly hidden beneath drift and only appears around Hollywater Farm (807343) and Long Down (809325) in Woolmer Forest; the top clay has been found by augering at the latter locality as a stiff, variegated sandy clay, but not at the former. It seems likely then that although the top clay occupies the same stratigraphical position as the Mare Hill Clay of Sussex, it is not in this area a continuous horizon. It may well be continuous from Woolmer Forest southwards into Sussex.

The next change to occur in the Puttenham Beds is the appearance of a very clayey horizon at the base. This is first found north-west of Headley, round about 817369, and is well developed in the neighbourhood of Headley Mill Farm and Reynold's Farm, between Lindford and Standford, where it appears in auger samples as plastic, extremely clayey sand. From here the very clayey horizon can be traced southwards along the western side of the Wey and the Hollywater. South-west of Standford considerably more of the beds are clayey, stiff silty brown clay being found by augering beneath the 300-feet gravel of Passfield Common near 815342, so that the very clayey material comprises here about half of the succession; above it come the fine to medium, very ill-graded, silty and clayey sands found in the western part of Passfield Common and near Hollywater Green, so that the whole succession has undergone a southward decrease in grain size.

These changes continue to the southern limit of the area mapped. Between Bramshott and Long Down, Woolmer Forest, the succession can be constructed with the aid of augering and of the cuttings on the military railway. The basal clay is represented by glauconitic, very clayey sand and is followed upwards by variegated grey and amber silty clay outcropping around Conford. The cuttings on the military railway show ill-graded, glauconitic, silty and clayey sand which is extremely clayey along the eastern side of Keeper's Hill (819330). At Holm Hills (821326) the cutting, on a slightly higher horizon, shows about forty feet of variegated grey, buff, orange and red clayey silts and silty sands. Above this come ill-graded silty fine sands, less clayey than those below, although with clayey patches, occupying Polecat Hill (815328) and the eastern slopes of Long Down. At the top comes the thin bed of sandy variegated clay representing the top clay horizon.

(iv) *Thickness and General Character of the Puttenham Beds*

East of Churt these beds have a thickness between 100 and 110 feet but this increases westwards to about 125 feet in the neighbourhood of Churt and Headley, south of which it expands to 140–150 feet.

It has not been found possible to distinguish the Upper and Lower Puttenham divisions recognised by Rogers & Richardson (1947) on the basis of mechanical analysis, and also by Kirkaldy (1932) in the Hascombe area to the east. Between Thursley and a little east of Churt the sands are fine but ill-graded throughout, while around Churt and westwards to a little beyond Headley the beds are very variable and the different types of sand recur without apparent stratigraphical order. According to Rogers & Richardson (*ibid.*, p. 268) the small percentages of coarse material present in the Upper Puttenham Beds around Hascombe are entirely absent further west around Green Cross and Churt; this in itself is not entirely true, but it must certainly not be taken to imply a uniform westward

diminution in grain size, since very coarse material is found at many different levels in the Puttenham Beds around Headley. A diminution in overall grain size takes place south of Headley.

Although at first sight the boundaries now drawn for the Puttenham Beds and those drawn for the Sandgate Beds by the original surveyors of Sheet 8, SW., of the Geological Survey appear very different, the lines do, in fact, correspond quite closely if it be borne in mind that the early surveyors, working up from the Sandgate Loams of Sussex, allowed the 'Sandgate Beds' to include the very clayey facies only and divided the coarser sands between the 'Folkestone Beds' and the 'Hythe Beds'. For example, they show the 'Sandgate Beds' as dying out to the north-east of Headley, pushing out a last narrow tongue of outcrop towards Wishanger; this narrow tongue was apparently drawn to include the clayey exposures between Headley and Huntingford Bridge, mentioned above. In this case the overlying limonitic sands of the Puttenham Beds were included in the 'Folkestone Beds' while the underlying limonitic sands of Prospect Hill were included in the 'Hythe Beds'.

(e) Folkestone Beds

This is the most uniform of the four sandy divisions of the Lower Greensand in this area and is throughout clearly divisible into Lower Folkestone fine, clean-washed sands and Upper Folkestone coarse, pebbly sands.

The outcrop enters the area mapped at French Hill, Thursley, where about six inches of very fine, rather hard, slightly ferruginous sandstone overlies the Puttenham Beds, without any sign of an actual break at the junction, and passes up into very fine, very well-graded quartz sand which becomes gradually very slightly coarser upwards (fine medium) with some irregular iron staining.

From French Hill to Thursley the Folkestone Beds form a small scarp overlooking the narrow vale of the Puttenham Beds. The summit of Kettlebury Hill (886393) is formed of very coarse, pebbly sands with well-developed ironstone while the fine sands form the southern slopes of the hill and this situation is characteristic of the Folkestone outcrop westwards, the coarse sands forming a line of hills, really a discontinuous scarp, namely Kettlebury Hill, the Devil's Jumps, Churt Common, Buttermilk Hill, Gum Hill and Heath Hill, while the fine sands form lower ground to the south. These hills probably owe their existence to the reinforcement imparted to the sands by localised development of bands of hard iron-sandstone, seen clearly at Kettlebury and the Devil's Jumps (869395).

The standard section in the Folkestone Beds of the area is that at the Huntingford Bridge sand-pit, Headley (821389), where, owing to the unusually high dip of nearly 30° , a large part of the succession is exposed:

UPPER FOLKESTONE

feet

10. Similar to 9 but lacking the strongly developed reticulate ironstone and containing some massive soft sandstone. Coarse and ill-graded, but less so than 9 and becoming slightly finer towards the top. Incipient ironstone formation seen. Pebbles comparatively rare top not exposed; estimated 30
9. Variegated ferruginous and light sands with strongly developed reticulate ironstone in fantastic forms. Ferruginous sandstone bands, six to nine inches thick, quite distinct from the irregular reticulate ironstone, run through the sand in two crossing directions dipping 12-17° ENE. and 50° NW. by W. Sand very coarse and ill-graded, with abundant scattered pebbles up to one inch in length; also phenoplasts and lenticles of fine soapy clay and haematitic clay. Current-bedding obscured by ironstone development 54
8. Abrupt incoming of ironstone at base, followed by very iron-stained, very coarse, ill-graded sand. Pebbly in parts, with pebbles of one-quarter inch diameter. Much haematite associated with reticulate ironstone. Current-bedded, with foresets of ten to twelve feet amplitude 25
7. Light-fawn and somewhat silvery firm sands, current-bedded, with foresets of two feet amplitude. Sand is coarse, ill-graded, with grains up to one-eighth inch. Thick and numerous irregular clay seams (one-quarter to one inch thick) occur along the bottom-sets. Between the clay seams is white sand with some mica; incipient ironstone formation is seen immediately beneath the clays. Pebbles, up to three-quarters of an inch long, occur along the foresets 8½
6. Soft sandstone, strongly current-bedded, comprising one set of foreset beds. Sand very coarse and ill-graded. Along the foreset laminae occur (a) pebbly layers with pebbles up to one-half inch long, (b) thin clay seams, (c) ferruginous sandstone seams a few inches thick 17
5. Rapid change at base to very coarse, ill-graded, iron-stained sand. Strongly current-bedded, comprising one set of foreset beds. Light-fawn very fine powdery clay occurs in three ways: (a) along the foresets, (b) as vertical seams cutting across the foresets, (c) as numerous scattered lenticular phenoplasts, one-half inch in diameter. Seams of finer sand also occur along the foresets. Occasional ironstone concretions of tubular 'box-stone' form seen 3-7

LOWER FOLKESTONE

feet

4. Firm sands, strongly current-bedded; in part iron-stained, in part silvery. Basal two feet consists of a long group of foresets full of extremely numerous irregular one-sixteenth inch thick clay seams. Occasional seams (of average thickness one-tenth inch) of very fine, soapy-textured, light pinkish-grey fuller's earth-like material, associated with fine, micaceous 'egg-timer' sand. Sand less well-graded and slightly coarser than group 3 (fine medium), with fair amount of mica 16

- | | | |
|---|--------|--------|
| 3. Current-bedded sand, with foresets of one and a half feet amplitude. Sand of about same grain size as group 2. Clay seams along foresets more irregular and contorted. More micaceous than groups 1 and 2 | | feet |
| 2. Fine, silvery, very slightly iron-stained sand; strongly current-bedded, with foresets two to three feet amplitude. Slightly coarser than group 1. Numerous clay seams of slightly purplish colour along the foresets are more regular and the clay more plastic than in group 1 | | 5-7 |
| 1. Silvery and light-fawn firm sands, very fine, well-graded and clean-washed. Occasional black specks (limonite?). Grey silty clay occurs in very irregular undulating seams, one-eighth inch thick, and also isolated, elongated phenoplasts. Some clay seams are very close together, giving a mass up to one inch thick predominantly of clay | | 11½ |
| | | seen 7 |

It is estimated that there are about eighty-five feet of the fine, well-graded sands beneath the base of the exposure and about ten feet of the highest group above the topmost seen, giving a total of 125 feet of Lower Folkestone and 150 feet of Upper. The fine sands are largely hidden beneath the terraces of the Wey but they emerge to form the outlier of Picket's Hill on the south bank (820384). These thicknesses seem to remain fairly constant throughout the area.

To the west of the Wey the same divisions can be traced. A pit at 812386, west of Baigent's Hill, shows extremely coarse pebbly sand, densely seamed with irregular reticulate ironstone; similar material appears in Messrs. G. A. Day's Bordon Sand Pit at Sleaford (804383) and in an old pit east of this (806384). On Broxhead Common the coarse sands form the higher ground, truncated by the 300-foot platform, and are exposed in several places, while the fine sands can be traced by augering along the south-eastern edge of the common.

South of Broxhead Common the Folkestone Beds outcrop continuously through Bordon and Whitehill but on the area mapped are mostly hidden beneath terrace deposits. The isolated outcrops which emerge through the drift in the Hollywater and Woolmer Forest districts are all of the fine sands. Quite a good section is given by the cutting on the military railway on the south side of Hollywater Clump (804334). On Horsebush Hill in Woolmer Forest (804328) soft dark-brown ferruginous sandstone of fine grain outcrops, associated with typical Lower Folkestone sands; near the top of the hill a trench was cut through lenticles of very coarse limonitic sandstone, full of large shiny pellets of limonite. The fine sands also outcrop on Long Down but can be found only by difficult augering through the 300-foot gravel. The coarse sands succeed, with abrupt oncoming of coarse ill-graded sand and coarse ironstone, on Fern Hill and Brimstone In-closure, outside the area mapped.

According to Rogers & Richardson (1947, 263) the Upper Puttenham Beds 'partake more of the characters of the overlying Lower Folkestone Beds than of the Lower Puttenham Beds. They are evidently a transitional facies. . . .' They state (*ibid.*, 268): 'There is relatively little difference between the lithological characteristics of the Upper Puttenham and Lower Folkestone Beds; both are essentially silty fine sands.' This latter statement is difficult to understand unless it is based solely upon the figures given by mechanical analysis without adequate field comparisons. The contrast is usually quite dramatic in the field as, for example, around Kettlebury and north-east of Churt, where the fine, ill-graded, dark and very silty sands, with shiny limonite grains, of the Puttenham Beds are clearly distinguishable from the well-graded, almost pure quartz sand of the Lower Folkestone Beds.

There is little evidence from the area north-east of Headley of any actual break at the Puttenham-Folkestone junction. Where the Puttenham top clay is present, i.e. on Broxhead Common and Long Down and also at French Hill, there certainly seems to be a sharp change of sedimentation. On the other hand, between the two first-named places there is evidence from the Horsebush Hill and Hollywater area of a transition. The coarse limonitic sandstone described above from the Upper Puttenham Beds of Headley Park is set in ill-graded medium silty sand. On Horsebush Hill there is found some very ill-graded coarse sandstone, with quartz grains ranging up to two millimetres, full of sub-sphaerical and discoidal polished grains of limonite up to four millimetres in diameter, and with large botryoidal grains of glauconite. This is a type which is 'more Puttenham than the Puttenham' but is associated here with fine, well-graded, clean-washed sand and soft, dark-brown, fine iron-sandstone, undoubtedly Lower Folkestone. A similar association was noted on Hollywater Clump. This is reminiscent of the Puttenham-Folkestone transition seen by Kirkaldy (1932, 138) at Highdown (Hydon) Ball, Hambledon, where 'large, rather purplish coloured clayey patches of sand . . . occurred for quite a distance up . . . in the normal clean-washed sands'.

The pebbles in the Folkestone Beds are mainly chert ('lydite') and quartz. A count of pebbles from bed 9 of the Huntingford Bridge pit showed 65% chert of various colours, including oolitic examples (Wells, *etc.*, 1947), 25% quartz, 10% limonite and ironstone.

4. STRUCTURE

The dominant feature in the structure of the area is, as has been recognised since the time of Fitton (1836), the Hindhead Anticline. Detailed mapping of the base of the Hythe Beds has contributed evidence towards knowledge of the form of this structure as shown on the map (Fig. 1).

The following points may be emphasised:

1. The base rises from 300 feet at Witley Station to 400 feet at Halnacker Copse (913375), below Rutton Hill, and is at 400 feet at 905376, between Rutton Hill and Blackhanger, and 500 feet at Holman Grove (901371).

2. The base is at 615 feet at the head of the Devil's Punch Bowl and falls northwards.

3. In the Stroatley valley between Hindhead and Inval the springs at the valley head are at approximately 660 feet and the base falls southwards. In the 'Lion' Valley to the west the base is everywhere below 500 feet but in the Nutcombe Valley it is at 500 feet below Nutcombe and falls steadily southwards.

Along the eastern side of the Portsmouth Road and Inval ridges, from Holman Grove to Haslemere, the base of the Hythe Beds has been much affected by slipping and cambering and its altitude is not necessarily relevant to the structure.

In addition to outcrop evidence there are the following well records:

	feet
Fintry, Brook (936381) Base of Hythe	285
Waterworks, Brook (926384) Base of Hythe	239
Corner Cottage, Bowler's Green (917383) Base of Hythe below	244
Reservoir, Hindhead (889358) Base of Hythe not far below ...	546
Water Tower, Hindhead (887359) Base of Hythe below	515
Dene End, Haslemere (896323) Base of Hythe	420
Upperfold, Hammer (859323) Base of Hythe	376

The base of the Hythe Beds is not exposed at Waggoner's Wells or in Whitmoor Bottom but cannot be far below the surface at the former.

Upon this evidence stratum contours have been drawn for the base of the Hythe Beds which show the Hindhead Anticline as a structure whose crest line passes beneath Gibbet Hill and whose axial trend is about 20° north of west. In an attempt to confirm this axial trend all dip readings which do not seem to have been affected by superficial movement have been plotted on a stereographic net (Fig. 4). The result is consistent with a picture of regional axial plunge of about 2° on a bearing 290° , with dips tending to be steeper towards the north than towards the south.

One or two interesting points emerge from consideration of the stratum contour map. Firstly, the synclinal depression to the south of the Hindhead Anticline does not correspond to the Haslemere Valley but is about one-third of a mile to the south of it, as already pointed out by Wooldridge (1950, 168). Secondly there is some indication of the position of the culmination of the Hindhead fold: Wooldridge (*ibid.*, fig. 4) indicates an inlier of the red clay division of the Weald Clay occupying the valley north-east of Grayswood, from 928354 to 943371, the boundary of which appears to fall steadily from nearly 250 feet at the head of the inlier to

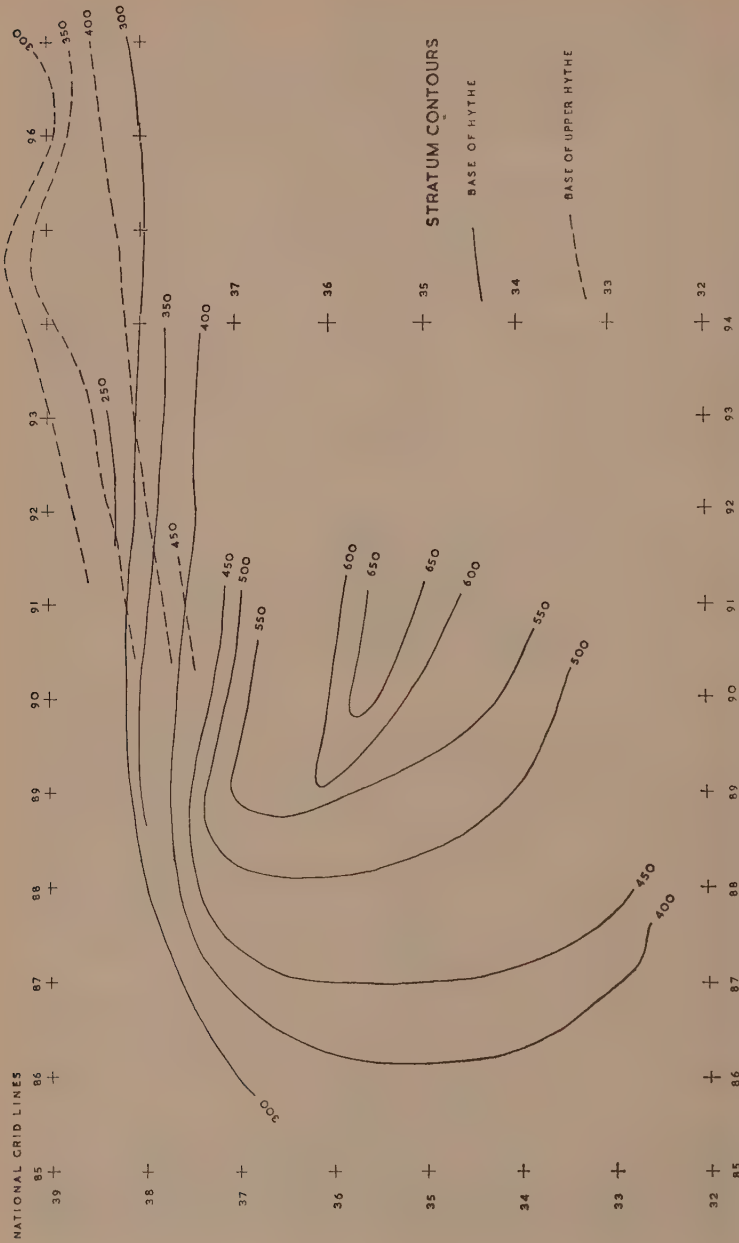


Fig. 3. Stratum contours drawn on the base of the Hythe Beds and, in the Witley area, of the Cherty Series of the Hythe Beds

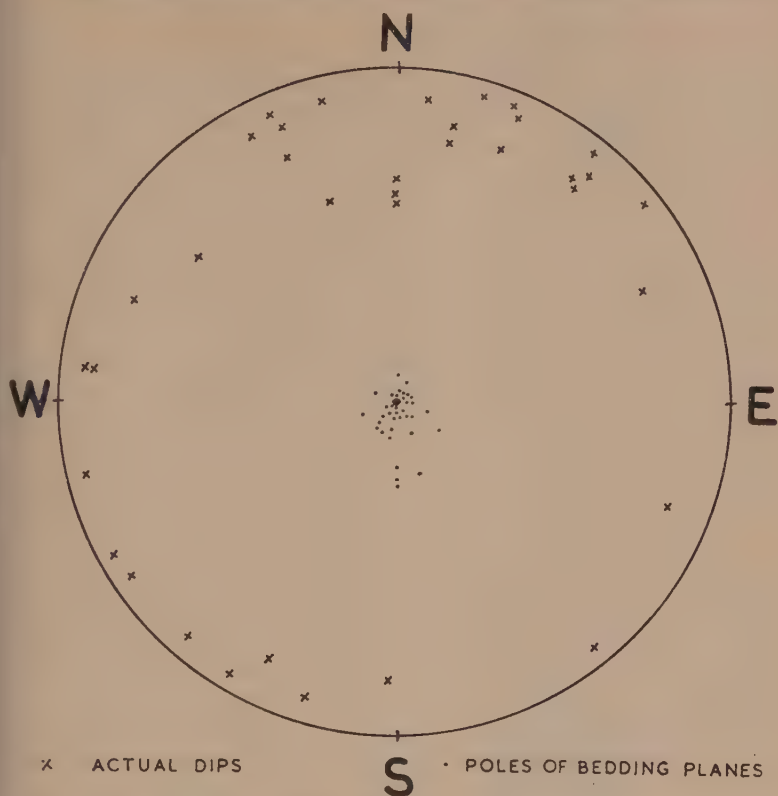


Fig. 4. Dips in the Lower Greensand plotted on a stereographic net. Apart from two anomalous readings, the actual dips have a parabolic distribution with its apex pointing about 20° north of west, while the poles of the bedding planes cluster in the opposite quadrant but with a markedly one-sided distribution. The suggestion is of a structure plunging at about 2° on a bearing of approximately 290° but with steeper dips to the north than to the south

somewhat below 200 feet at the northern end: the drainage pattern surrounding Hindhead is remarkably radial; the Small Brook and Cosford streams drain northwards, the streams near Witleypark Farm (918368), probable former headwaters of the Brook stream, drain north-north-eastwards and the stream with the inlier of red clay just mentioned, which is a probable former headwater of the Witley stream, drains north-eastwards (see also p. 234). These facts put together seem to suggest that the anticlinal culmination lies between Gibbet Hill and Stroud (920351), north of Grayswood.

The Hindhead Anticline is a broad, gentle, composite structure which,

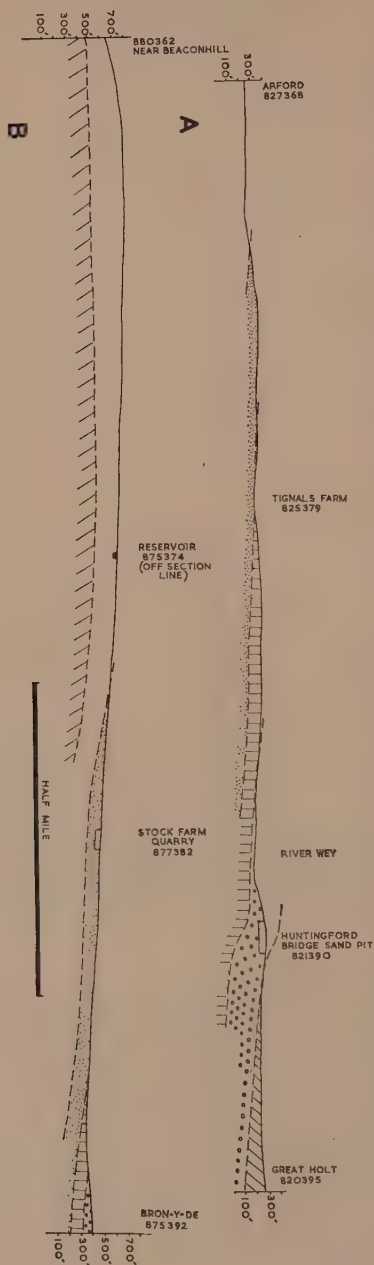


Fig. 5. Two true-scale sections to show local flexures on the northern flank of the Hindhead Anticline. Ornamentation as in Fig. 1

taken as a whole, shows the common tendency of anticlines in south-east England to be asymmetrical, with steeper dips on the northerly limb, but the relatively steeper northerly dips in this case are not found over the whole of the northern limb but are confined to narrow and local zones of steeper dip, so that the northern limb consists of alternating long stretches of very gentle dip and short stretches of steeper dip (Fig. 4). These sharp 'roll-overs' of dip are found in three main areas:

(a) Along the foot of the Brook escarpment. The Weald Clay dips at 11° in the Brook Brick-pit and the Hythe Beds at $10\text{--}15^\circ$ at 913377, near Rutton Hill. Almost due west of this area but probably slightly *en echelon* is another zone of steepened dip giving dips of 10° in the Hythe Beds in the Small Brook near 891378 and carrying the base of the Bargate Beds below the floor of the Stock Farm and Green Cross pits, implying again a dip of 10° compared with the usual local $2\text{--}4^\circ$.

(b) A local zone of high dips carries the Folkestone Beds beneath the Gault to the north of Headley, giving dips of nearly 30° in the Huntingford Bridge sand-pit.

(c) The most clearly marked zone of high dip is that which forms the southern limb of the Thursley Syncline (Kirkaldy, 1933b) and can thus be regarded as bounding the Hindhead Anticline on the north. This is approximately in line with the zone mentioned above (b) but it seems unlikely to be continuous with it. The effect of the increase in dip can be seen in the narrowing of the Puttenham Bed outcrop between the 'Pride of the Valley' and Thursley but the most westerly clear exposures of steeply dipping beds are at 898398, just west of Thursley village, where both Lower and Upper Folkestone Beds are exposed dipping 14° at 011° . Eastwards from here the outcrop of the Puttenham Beds is very narrow and at French Hill the Puttenham-Folkestone junction dips north at $41\text{--}45^\circ$, while just to the south, near Heath Hall, the Bargate Beds dip 10° at 011° . High dips do not occur uniformly along this line, however, since near the 'Red Lion' (907396) the Folkestone Beds dip at only a few degrees; this suggests that the high angle of dip may not be the only factor restricting the width of the Puttenham Bed outcrop. Furthermore, at French Hill the Puttenham outcrop is only 125–130 feet wide, which seems insufficient to contain the full thickness of the beds even at 45° ; thus a strike fault is suggested here, which may also explain the steep northerly dip at French Hill as compared with the dips on a bearing of 011° near by.

Kirkaldy (1932) shows a similar pattern of local northward flexures in the Hascombe area to the east. The Great Enton flexure marked on his map (*ibid.*, pl. 7) is directly in line with the southern limb of the Thursley Syncline at French Hill and is probably continuous with it, as the Puttenham Bed outcrop remains very narrow between the two points.

The Thursley Syncline is a markedly asymmetrical structure, since its northern limb has a very gentle dip, as can be seen in the area of Witley, Thursley and Hankley Commons, examined but not mapped in detail by the authors. It is particularly well seen in the valley east of the Lion's Mouth (887414) on Hankley Common. Here the Puttenham-Folkestone junction is easily mappable and is practically horizontal.

5. SUPERFICIAL STRUCTURES

The large-scale superficial structures in the area include not only land-slipping but also forms akin to cambers and valley-bulges (Hollingworth, Taylor & Kellaway, 1944). Such effects develop mainly above and in a thick clay horizon and in this area have been observed only near the junction of the Hythe Beds with the underlying clay.

Along the whole eastern side of the Inval ridge this junction seems to be between 50 feet and 100 feet lower than its expected level. In the Stootley Valley, between Hindhead and Inval, where there is no apparent sign of superficial movement, the junction descends at a gentle angle from about 660 feet in the north to 500 feet near Great Stootley (894339), whereas on the eastern side of the ridge the junction is consistently depressed along equivalent lines of strike. Along a strike line passing through Keffold's (905349), for example, the base is at 600 feet in the Stootley Valley, 558½ feet in the well at Keffold's and 550 feet on the eastern side of the ridge. This could be explained either by a tectonic warp or dislocation, trending north-south, or by some form of superficial movement. Any monocline or fault downthrowing to the east along this line could be expected to pass beneath Boundless Copse and the col east of Gibbet Hill to affect both the clay-Hythe and Hythe-Bargate boundaries in the neighbourhood of Blackhanger. Detailed mapping has not revealed evidence of displacement of either boundary, although the base of the Hythe just here (Holman Grove) is affected by small-scale slipping and the evidence is obscure. It is of interest to note that Mr. P. Straus (personal communication) did map the Bargate base as affected by a dip fault downthrowing to the east at this very point, immediately west of Blackhanger, but the authors, after re-examining the ground, were unable to agree with him. Another possible piece of evidence favouring a tectonic interpretation is Drew's record (Topley, 1875) of a fault, throwing about sixty feet to the east, in the Haslemere railway cutting at the southern end of the Inval ridge, although the fault is marked on the Old Series map as running parallel to the railway with a south-west to north-east trend. The nature of the structure in the cutting is difficult to judge now in the absence of exposures and Wooldridge (1950) suggests that the records point to valley bulging as the explanation.

The topography of the eastern side of the Inval ridge argues strongly for multiple landslipping or cambering as the main factor in the depression of the base of the Hythe Beds here and the authors, on the whole, prefer the hypothesis that any dislocation involved is superficial, although recognising that arguments in favour of some kind of tectonic dislocation are strong. The fact that it seems possible to locate Atherfield Clay by augering along practically the whole length of the ridge suggests possibly that the movement has been of the cambering type here rather than rotational slipping of the type seen at Tilburstow Hill (Gossling & Bull, 1948), where the Hythe Beds rest on Weald Clay, but an example of this type occurs at Hurt Hill, at the northern corner of the ridge, where augering found Weald Clay next to the sand.

The geological situation around Gibbet Hill is highly favourable to superficial movement, since the Hythe Beds have considerable relief and rest on a very thick mass of clay. The general impression is that the overlying beds have 'sagged' in all directions owing to the collapse of the clay beneath, the 'sagging' taking the form in some places of rotational slipping (inward dip) and in others of cambering (outward dip). Wooldridge (1950) has given arguments for regarding most of this movement as of Pleistocene date.

The effects of movement of the cambering type can be seen to the north of Gibbet Hill. In Boundless Copse (901365) stone bands were observed dipping east-north-east, i.e. towards the clay, at angles averaging 25° . Along the Portsmouth Road immediately west of here the beds dip consistently towards the clay, eastwards on the east side of the ridge, westwards towards the Devil's Punch Bowl on the west side, at angles varying from 12° to 40° . In the Devil's Punch Bowl itself the clay outcrop is almost completely masked by slipped Hythe material; here the phenomenon of multiple spring lines is well shown and the highest spring line has been taken as the true top of the clay. The boundary mapped in this way by the evidence of seepages and vegetation change can fortunately be occasionally checked by augering where the cover of slipped sand is thin and a schedule of localities where clay has been found is given here:

- 89503605 Several auger holes just south-west of the main eastern spring.
- 89153630 Near the junction of the two headwater streams.
- 89203640 At the head of the first tributary stream.
- 88953675 The junction of paths one-sixth mile south of the ruins of Highcomb Farm.

There is some evidence of cambering along the northern side of the inlier of clay in the Haslemere Valley. Exposures in the Hythe Beds near Wey-springs (891331) show unusually high southerly dips (10°); at Critchmere

(878329) sandstones belonging to group 2 of the Hythe Beds (p. 210) dip south-west at $16-20^\circ$ on the south side of the road, i.e. towards the clay, whereas the general dip in the Hythe Beds in this section is south-south-west at about 4° . The two faults seen in the Critchmere section (p. 210), which have a combined throw of at least thirty-five feet, may conceivably be due to large-scale dip and fault structure here. In an old quarry at 864325, west of the 'Prince of Wales' at Hammervale, the Hythe Beds dip south-south-west at 15° although the clay is here not exposed in the valley bottom; the record of the well at Upperfold (p. 227), however, suggests that the clay ought to be exposed here and that the Hythe infilling of the valley bottom may itself be due to cambering.

6. THE FORM OF THE MAIN HYTHE SCARP AND THE ORIGIN OF THE RIGHT-ANGLED BEND

The change in trend of the Hythe scarp, from approximately east-west to approximately north-south, which takes place at Blackhanger, is due to the presence of the Hindhead Anticline, flanked on the south by the synclinal area of Haslemere, but two anomalies remain: firstly the fact that the anticlinal axial plane crosses the Hythe scarp not at or near the right-angled bend but about a mile to the south of it, and, secondly, the very abrupt nature of the right-angled bend itself.

If we were to imagine the Hindhead Anticline restored, so that the cover of Hythe Beds could be seen extending further eastwards over the clays than it does now, we should expect to find that transverse consequent streams draining its northern flank had breached the Hythe Beds and exposed the clays in deep, broad valleys like the Punch Bowl but with larger and deeper exposures of the clay eastwards owing to the higher structural level of the base of the Hythe Beds relative to base level. The deep amphitheatre-like basin, floored by Weald and Atherfield Clay covered by much Hythe Bed debris, and surrounded on three sides by steep slopes of Hythe Beds, which lies immediately south of Blackhanger, that is the area between Blackhanger, Boundless Copse, High Button (907363) and Rutton Hill (909376), seems to be the remains of one of these former 'Devil's Punch Bowls' that was eroded by the consequent Cosford Stream. Further east there was probably another and wider clay-floored valley drained by the now-vanished consequent headwaters of the Brook stream and, further east again, the position of that drained by the former consequent headwaters of the Witley stream is perhaps marked by the inlier of the red clay division of the Weald Clay shown by Wooldridge (1950, fig. 4) north of Grayswood.

The floor of these valleys is represented by the area between the twin scarps of the Hythe Beds between Brook and Blackhanger. The upper

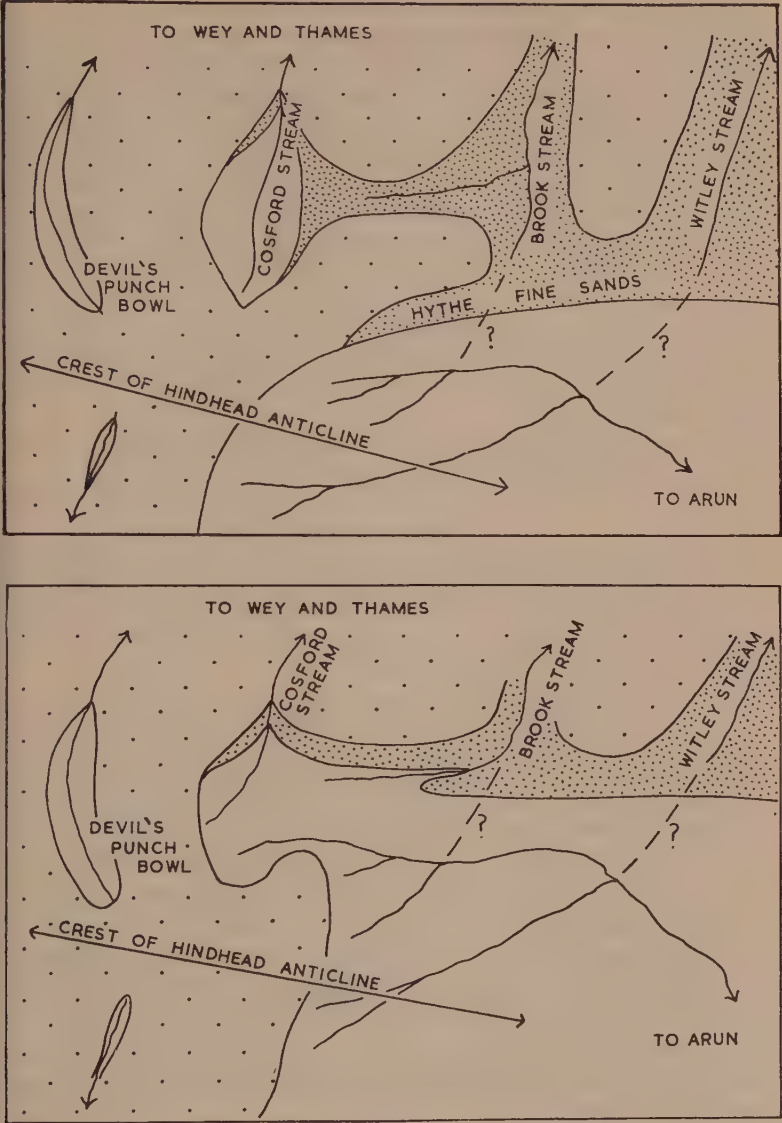


Fig. 6. Diagrammatic maps of two stages in the drainage history of the country between Witley and Hindhead, showing the development of the right-angled bend in the Lower Greensand scarp by secondary consequent denudation of the northern flank of the Hindhead Anticline and river capture by the southward-flowing streams

scarp is that formed by the cherty division of the Hythe but the lower scarp is not that of the fine sands of Witley since, although near Brook it has a capping of those beds, this capping has been removed further west, towards Blackhanger, and a conspicuous escarpment, entirely in clay, remains which is the watershed between the remnants of the old south to north drainage plan and the piratical headwaters of the Arun. It is the latter, although probably they were at the time still tributary to the Wey and had not been captured by the Arun (Bury, 1910), which have destroyed the eastern wall of the clay basin south of Blackhanger and captured part of the former catchment area of the Cosford stream and all that of the headwaters of the Brook stream. The eastern wall of the Blackhanger basin had probably already been breached, before the depredations of the south-east flowing streams destroyed it, by a subsequent tributary of the Brook consequent, which now remains as the subsequent portion of the Brook stream, west of Brook.

The diagrams (Fig. 6) suggest the possible process of formation by these events of the anomalies before mentioned.

7. CONCLUSIONS

(1) All the sandy subdivisions of the Lower Greensand in the area, except the Folkestone Beds, are highly variable in lithology.

(2) Within the area the Folkestone Beds are constantly divisible into lower fine sands and upper coarse sands.

(3) There is evidence that the Hythe Beds have undergone decalcification.

(4) All the subdivisions of the Lower Greensand up to and including the Puttenham Beds thicken from north to south. The original thickness of the Lower Greensand probably increased from about 600 feet at the northern margin to about 850 feet at the southern margin of the area.

(5) The Hindhead Anticline has an axial trend about 20° north of west and a regional axial plunge of about 2° . Its northern limb is marked by localised zones of increase in dip, arranged *en echelon*. The southern limb of the Thursley Syncline consists of such a flexure which has become a strike fault; this marks the northern boundary of the Hindhead Anticline.

(6) Large-scale superficial structures include land-slips, cambers and valley-bulges, which occur along the junction between the Hythe Beds and the underlying clay.

(7) The right-angled bend in the Hythe scarp at Blackhanger has been caused by secondary consequent denudation of the northern flank of the Hindhead Anticline coupled with headward erosion by the tributaries of the Arun.

ACKNOWLEDGMENTS

The authors wish to express their gratitude to Dr. J. F. Kirkaldy for first suggesting work on this area, for access to manuscript notes of E. A. Turner and for critically reading the manuscript; they thank Mr. J. Clegg of the Haslemere Educational Museum and Mr. P. Straus of Hindhead for assistance, and Dr. R. Casey for fossil identifications; they express their appreciation of those landowners, farmers and quarry-owners who have permitted them to enter their property and their apologies to many others for trespassing. Miss E. Harvey has drawn the map (Fig. 1).

REFERENCES

- BURY, H. 1908. Notes on the River Wey. *Quart. J. geol. Soc. Lond.*, **64**, 318–34.
 ———. 1910. The Denudation of the Western End of the Weald. *Quart. J. geol. Soc. Lond.*, **66**, 640–92.
 CHAPMAN, F. 1894. The Bargate Beds of Surrey and their Microscopic Contents. *Quart. J. geol. Soc. Lond.*, **50**, 677–730.
 DINES, H. G. & F. H. EDMUNDS. 1929. The Geology of the Country around Aldershot and Guildford. *Mem. geol. Surv. U.K.*
 FITTON, W. H. 1836. Observations on some of the Strata between the Chalk and the Oxford Oolite in the South-east of England. *Trans. Geol. Soc. Lond.*, 2nd ser., **4**, part 2, 103–389.
 FOWLER, BINSTED. 1895. The Hythe Beds of the Lower Greensand in the Liphook and Hindhead District. *Proc. Geol. Ass., Lond.*, **13**, 361–5.
 GOSSLING, F. & A. J. BULL. 1948. The Structure of Tilburstow Hill, Surrey. *Proc. Geol. Ass., Lond.*, **59**, 131–9.
 HOLLINGWORTH, S. E., J. H. TAYLOR & G. A. KELLAWAY. 1944. Large-scale Superficial Structures in the Northampton Ironstone Field. *Quart. J. geol. Soc. Lond.*, **100**, 1–44.
 HUMPHRIES, D. W. 1953. *The Lithology and Conditions of Deposition of the Lower Greensand of the South-west Weald*. Thesis, London University.
 KIRKALDY, J. F. 1932. The Geology of the Country around Hascombe, Surrey. *Proc. Geol. Ass., Lond.*, **43**, 127–51.
 ———. 1933a. The Sandgate Beds of the Western Weald. *Proc. Geol. Ass., Lond.*, **44**, 270–311.
 ———. 1933b. The Tectonic Development of the Western Weald in Lower Cretaceous Times. *Geol. Mag.*, **70**, 254–68.
 ———. 1939. History of the Lower Cretaceous Period in England. *Proc. Geol. Ass., Lond.*, **50**, 379–417.
 ———. 1948. Field Meeting in the North-west Weald. *Proc. Geol. Ass., Lond.*, **59**, 174–5.
 ——— & F. A. MIDDLEMISS. 1954. Field Meeting in the Hindhead Neighbourhood. *Proc. Geol. Ass., Lond.*, **65**, 175–7.
 ——— & E. A. TURNER. 1930. Field Meeting at Witley and Hascombe. *Proc. Geol. Ass., Lond.*, **41**, 217–19.
 ——— & S. W. WOOLDRIDGE. 1938. Notes on the Geology of the Country around Haslemere and Midhurst. *Proc. Geol. Ass., Lond.*, **49**, 135–46.
 LEIGHTON, D. 1915. Report of an Excursion to Hindhead. *Proc. Geol. Ass., Lond.*, **26**, 88–9.
 LINTON, D. L. 1930. Notes on the Development of the Western Part of the Wey Drainage System; together with a report of the Field Meeting at Bordon and Alton, Hants. *Proc. Geol. Ass., Lond.*, **41**, 160–74.
 MURCHISON, R. I. 1826. Geological Sketch of the North-western extremity of Sussex, and the adjoining parts of Hants and Surrey. *Trans. Geol. Soc. Lond.*, 2nd ser., **2**, part 1, 97–107.

- RICHARDSON, J. A. 1947. Chert Formation in the Bargate Beds of the Churt Neighbourhood, Surrey. *Proc. Geol. Ass., Lond.*, **58**, 161-77.
- ROGERS, H. S. & J. A. RICHARDSON. 1947. Mechanical Analysis of the Lower Greensand of North-west Surrey. *Proc. Geol. Ass., Lond.*, **58**, 259-69.
- TOPLEY, W. 1875. The Geology of the Weald. *Mem. geol. Surv. U.K.*
- WELLS, A. K. *et al.* 1947. Studies of Pebbles from the Lower Cretaceous Rocks. *Proc. Geol. Ass., Lond.*, **58**, 194-258.
- WHITE, H. J. OSBORNE. 1910. The Geology of the Country around Alresford. *Mem. geol. Surv. U.K.*
- WOOD, G. V. 1957. The Heavy Mineral Suites of the Lower Greensand of the Western Weald. *Proc. Geol. Ass., Lond.*, **67**, 124-37.
- WOOLDRIDGE, S. W. 1928. Chapter on Lower Greensand in the Report of the Weald Research Committee. *Proc. Geol. Ass., Lond.*, **39**, 223-37.
- . 1950. Some Features in the Structure and Geomorphology of the Country around Fernhurst, Sussex. *Proc. Geol. Ass., Lond.*, **61**, 165-90.
- & D. L. LINTON. 1955. *Structure, Surface and Drainage in South-east England*. London.

Field Meeting in the Hindhead Area

Together with notes on the terraces of the River Wey

10-12 May 1957

Report by the Director: F. A. MIDDLEMISS

Received 14 January 1958

IN THIS REPORT the solid geology is dealt with in outline only, since all the exposures are described by Knowles & Middlemiss in the previous paper (p. 205).

Seventeen members attended the week-end meeting, the headquarters being at the Timberscombe Guest House, Fernhurst, where the Director gave an introductory talk on the Friday evening.

On the Saturday morning the party motored to Weydown Common (903345)¹ and ascended the Inval ridge which, in fine weather, provides a magnificent view over the Weald. Here the landslipping and cambering which affect the base of the Hythe Beds were pointed out and discussed. After the presence of clay and of a spring line in the valley to the west of Inval had been demonstrated, the party climbed to the summit of Gibbet Hill (900359) where the form of the Hythe Bed scarp and its change of strike at Blackhanger were seen.

The Devil's Punch Bowl, to the north of Gibbet Hill, is perhaps the most striking single physiographic feature of the area. In essence it is a typical transverse consequent valley, breaching the northern limb of the Hindhead anticline, the crest of which, although apparently bevelled by the Mid-Tertiary erosion surface (Wooldridge & Linton, 1955), making the present pattern strictly resequent, probably always functioned as a watershed. The special features of the valley, its bowl-like cross-section and abrupt combe-like head-slopes, are due to the exposure of the clay and the contrast between that and the Hythe Beds which gives rise to powerful spring sapping and to landslipping and cambering. These features are repeated in a less conspicuous way in the Stroatley Valley, between Hindhead and Inval, which possesses an abrupt, bowl-like head, but here, owing to the more gentle dip, the stream has breached the Hythe Beds throughout its course, hence the gorge-like exit from Highcomb Bottom (the northern extension of the Punch Bowl) is absent here.

¹ All grid references lie in the 100 Km. sq. 41 (SU).

The presence of clay near the head of the Punch Bowl was demonstrated, after which the party made its way northwards, with some difficulty, through the Small Brook gorge, seeing the successive exposures of the Hythe and Bargate Beds, as far as Ridgeway Farm (894386) and thence by lanes to Kettlebury Hill (886393), where the coarse upper sands of the Folkestone Beds were seen and also the fine view northwards. Here the coach was rejoined and, after lunch at the Pride of the Valley Inn, Churt, the afternoon was spent in examining the Bargate Beds in Stock Farm quarry (877382), the Folkestone Beds of the Huntingford Bridge sand-pit (821389) and the fossiliferous Puttenham Beds at Headleywood Farm (814373).

On the Sunday morning the party drove first to Critchmere (878329) and walked up the road to Woolmer Hill (877332), examining the extensive road section in Hythe Beds, and then made a tour on foot of Waggoner's Wells and Bramshott, during which the excellent exposures of Hythe Beds at 857342, 845332, and 841329 were seen. After lunch at the Passfield Oak Inn (821337) the fringes of Woolmer Forest were entered and the large exposure of Puttenham loams in the Holm Hills cutting (821326) examined.

Finally, the party drove southwards to Hollycombe (851294) where a roadside exposure of Hythe Beds of rather different facies was seen, and the week-end was rounded off by an ascent of Telegraph Hill (867264), near Woolbeding, where the weather was ideal for demonstrating the splendid view, possibly the finest geological view in the south of England. On returning to the guest-house the party had tea, during which Mr. J. M. Hancock proposed a vote of thanks to the Director.

On both Saturday and Sunday afternoons much was seen of the terraces of the Wey in the Headley and Passfield districts and their deposits. Three terrace levels can be recognised as intimately connected with the present course through the area of the river and its tributaries, as distinct from the high-level erosion surfaces around Hindhead which can be seen but which await investigation.

(i) *The Flood Plain*

The river is in most places considerably incised into the lowest or 'flood plain' surface. At Huntingford Bridge the surface of the feature is at 200 feet O.D. A short distance downstream, where the river is eight feet below the plain surface, the deposits are exposed and seen to consist of clayey, silty sand, mottled buff and orange, with vertical ferruginous root-casts. Bedded ferruginous and carbonaceous sandy silts are exposed between Headley Park and Lindford Bridge (809368), where the surface is at 218 feet O.D. Along the Wey itself the flood-plain feature ends upstream by an indistinct knick-point at about 260 feet O.D. at the mill (819344) between Standford and Passfield. Along the Deadwater and Hollywater the

same feature can be traced up to a point (814335) at about the same level just above Hollywater Pond, with several exposures of the silts in the stream banks.

(ii) *The First Gravel Terrace*

This, although parallel to the flood-plain, covers a wider area. Near Huntingford Bridge the front is about twelve feet above the surface of the flood-plain, the surface of the terrace having a slight slope upwards away from the river, and this difference in level is maintained upstream to beyond Lindford, above which it decreases. South of Hollywater this surface occupies a wide area of Woolmer Forest at about 260 feet O.D.

The terrace differs strikingly from the flood-plain in the nature of its visible deposits, which consist of coarse gravels and sands, seen, for example, by the roadside at 817386, near Brockford Bridge. A better exposure is by the riverside at 805364, near Lindford, where the gravel is ferruginous, consisting of coarse red sand full of fragments, one inch in diameter and smaller, of both cherty sandstone and flint. A similar exposure on the Hollywater at 818333, near Conford, shows cherty sandstone and brown flint in medium sand.

At Hollywater Farm (808343) a level continuous with the terrace can be mapped round an apparent meander core, suggesting a course of the stream abandoned during this stage. A similar feature surrounds Lindford but in this case it appears probable that the abandoned course may have been the original consequent course of the Bramshott Wey, captured at Headley Mill (813357) during the period of development of the terrace by a tributary of the Deadwater.

The area of the terrace level in Woolmer Forest has some peculiar aspects. In the first place there is no sign of gravel here, the deposit being a distinctive type of sand, clean-washed and very ill-graded and completely lacking in coloured constituents. Augering in Linchborough Park (806332) showed at least three and a half feet of this overlying the Puttenham Beds. In Forkedpond Enclosure (815321) some feet of it cover the surface of a level area stretching south to Weaver's Down (812306). Gravel is not found except along the course of the Hollywater near Conford, as noted above. It seems that the deposit of the terrace in the north-eastern part of Woolmer Forest was derived entirely from the Folkestone Beds, while that of the Hollywater includes material from the Hythe Beds to the south-east and from pre-existing flint-bearing gravels. The topography of Woolmer Forest, with its isolated flat-topped hills and indefinite drainage pattern, is difficult to explain. It was discussed by Linton (1930) who suggested that it was due to the irregular cementing of the iron-pan in the Folkestone Beds; much of the ground under consideration is, however, on the Puttenham Beds. The topography much resembles that of Thursley and Hankley

Commons, north of Kettlebury Hill, where also the Puttenham Beds emerge from beneath the Folkestone Beds at a very gentle angle of dip.

(iii) *The '300-foot' Terrace*

This is the most widely developed and impressive of the terrace features which follow the Wey. It caps the flat-topped hills which stand above the sand-covered 'first gravel' level in Woolmer Forest, forms Passfield Common and extends past Passfield and Headley to a well-marked 'back' in the region of Upper Passfield (832349). Further north the surface is more dissected but outliers are found at Broxhead Common, Picket's Hill, Hills Copse (831379), Wishanger Common and Furze Hill (848390). The 'back' of the terrace feature falls from about 390 feet at Bramshott to about 350 feet at Headley, indicating a gradient generally similar to that of the first two terrace levels.

The terrace deposits can be seen in several places. On Long Down (810325) brown-flint gravel, three to four feet thick, forms the surface. On the east side of Passfield Common is a large gravel pit (829335) showing at least four feet of coarse gravel consisting of fragments up to four inches in diameter of cherty sandstone, chert and ironstone in ill-graded, clean-washed sand with large quartz grains and large grains of glauconite and limonite; no flint appears to be present. Thus in the southern area the 300 foot surface bears two distinct streams of derived material, one coming from the south-west, carrying flint from the chalk of the Hawkley area, now absorbed into the catchment of the Rother, the other carrying chert from the Hythe Beds outcropping to the south and south-east. The two streams were separated by a watershed now represented by Weaver's Down and by the relatively high ground between Conford and Bramshott and must have converged in the neighbourhood of Passfield Common.

The chert-bearing gravels cover the fields between Passfield and Upper Passfield and were exposed in a temporary excavation at Headley Grange (826356). Northwards mixed chert and flint gravels are found. At Headley, immediately north of the Recreation Green (825364), are extensive old pits in which only cherty sandstone and sand could be found, but thirty years ago the degraded pit in which the village hall now stands exhibited a section described by E. A. Turner (in MS.) as showing fifteen to sixteen feet of evenly bedded gravel with sand lenticles; he estimated the pebble content at 18% flint, 20% ironstone, the rest chert and cherty sandstone and tiny quartz pebbles. A pit at Arford, presumably that at 828366, was described by Turner as in bedded gravels, mostly chert but with a small proportion of brown flint.

REFERENCES

- LINTON, D. L. 1930. Notes on the Development of the Western Part of the Wey Drainage System; together with a report of the Field Meeting at Bordon and Alton, Hants. *Proc. Geol. Ass., Lond.*, **41**, 160-74.
- WOOLDRIDGE, S. W. & D. L. LINTON. 1955. *Structure, Surface and Drainage in South-east England*. London.

Summer Field Meeting in Southern Ireland, 1957

29 August – 4 September

By J. C. BRINDLEY and W. D. GILL

Received 17 February 1958

INTRODUCTION AND SUMMARY OF THE GEOLOGY OF AREAS VISITED

THE MAIN OBJECTS of the meeting were to see the Carboniferous rocks and structures in the west of Ireland, and the Palaeozoic formations in the south of the country.

General Outline of the Geology of County Clare (W. D. Gill)

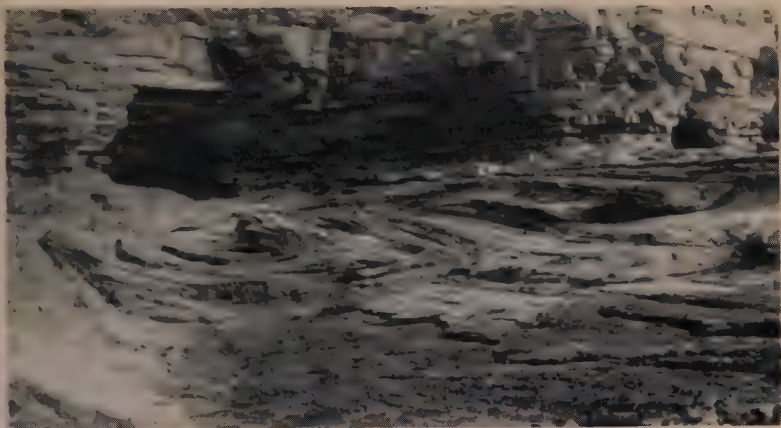
Overlying the Carboniferous Limestone in the West Clare Basin (Fig. 1) are some 1500 to 3500 feet of dark shales and siltstones with subordinate cleaner sandstones rarely more than 100 feet thick. The predominating dark shaly lithology and the common occurrence of very thin seams (two to eight inches) of anthracite, led the pioneer surveyors of 1860 (*Geological Survey of Ireland*) to classify the beds as Coal Measures. The attempt, in 1881, to subdivide this series into Yoredale Shales, Millstone Grit and Coal Measures without re-surveying the ground produced gross errors and should be ignored.

Stratigraphy

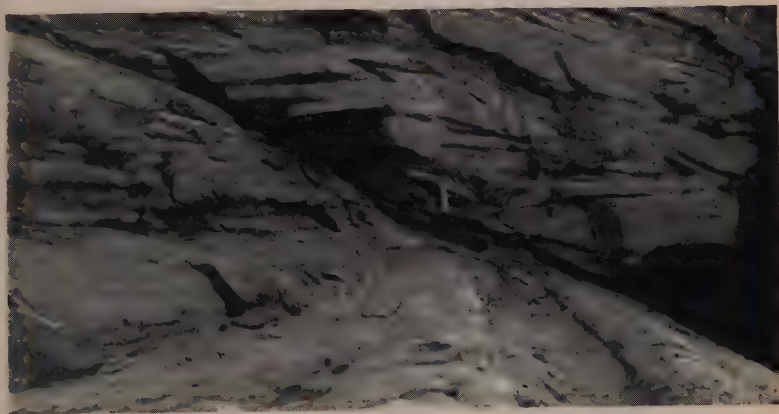
The researches of Dr. F. Hodson (1954a, b) in North Clare and at Foynes Island, and of the writer, who has mapped a strip five to ten miles deep along the Atlantic Coast, have established the succession shown in columnar sections in Fig. 2. The highest marine beds preserved in this area contain *Reticuloceras superbilingue* marking the R₂ stage.

The main points of stratigraphical interest are:

- (1) The very expanded thickness of the R₁ stage, compared with the very condensed succession of the H stage, which yields an abundance of exquisitely preserved solid goniatites, described by Dr. Hodson (1954a).
- (2) The northerly overlap at the base of the Namurian by which the E₂ and possibly lower zones at Foynes Island are cut out in north Clare and the lowest zone of H is ultimately missing in the extreme north on Slieve Elba (Hodson, 1954a and b).



A. Recumbent slump folds: Fisherstreet Bay. Cliff is 15 feet high



B. Major Shear plane at margin of channel slump: Fisherstreet Bay



C. Plug and crater of sand Volcano: Freagh Point

(3) The marked northerly attenuation of both H and R₁ stages. The entire succession in the south is about 3500 feet thick along the River Shannon, and the same range of beds is not more than 1300 feet thick in north Clare.

Slumps and Sand Volcanoes

It is probable that the rate of sinking of the trough along the line of the River Shannon was greater than the filling by sediment giving rise to an unstable subaqueous slope. This is testified by the abundance and variety of slump structures which have been investigated in detail by the writer in the many excellent exposures along the coast. There are at least twenty different horizons of major slump sheets or channels. The sheets vary from one to twenty feet thick and the channels, with sheared margins, are up to 1200 feet across and 150 feet deep. Channels may be isolated or in complex sheets. The variety of external form is matched by an even greater variety in the degree and style of internal deformation. Plastic-style deformation gives recumbent folds (Plate 3, A) and shear planes (Plate 3, B) closely resembling Alpine nappes. The majority of slumps show break-up into rafts of various sizes or the common sandstone balls floating in a churned-up matrix.

The majority of the slumps were more or less planed off by erosion by waves or currents before the onset of renewed normal deposition, but some of the slump channels ploughed up to twenty-five feet into surrounding sediments and have a complex history of filling by current-borne sediment. Others show repeated movement of settlement during the deposition of thirty feet of strata.

Resting on the eroded tops of many slumps of all types other than sheets less than three feet thick, are the sand volcanoes described by the writer to the Geological Society last year, and the subject of a joint paper with Professor Kuenen (Gill & Kuenen, 1958).

These volcanoes, the first of their kind to be described, and possibly unique in their size, abundance and beauty of preservation, are considered to have been built by sediment-laden subaqueous spouts of water rising from the settling masses of slumped sediment. Plate 3, C shows the excavated plug and crater of a cone on the sheet at Freagh Point.

Structure

The clarity and excellence of preservation of the sedimentary structures reflects two main factors:

- (1) The small degree of tectonic deformation.

The structure of west Clare is indicated by the pattern of outcrop of the *R. stubblefieldi* marine band shown on Fig. 1.

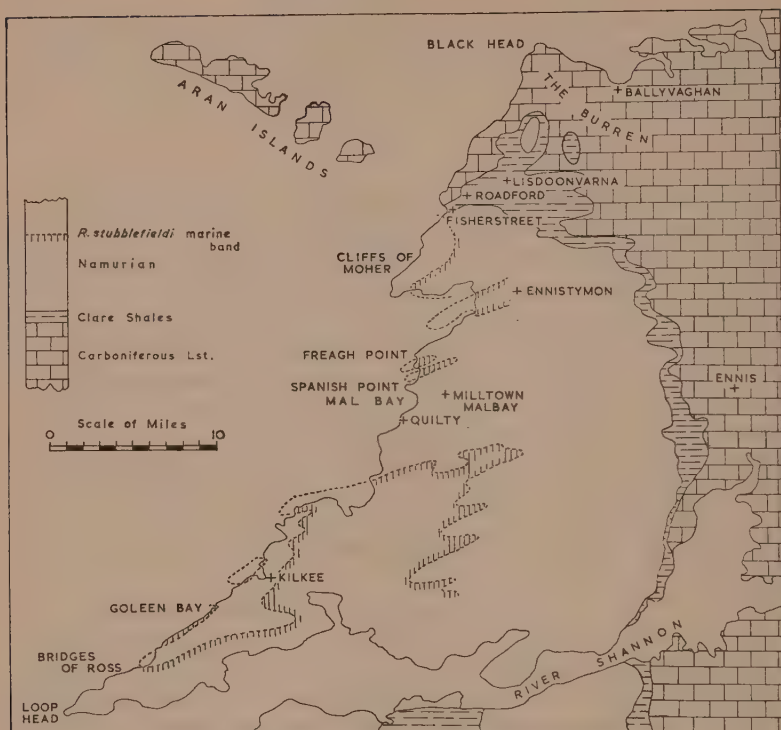


Fig. 1. Map of the West Clare Namurian Basin

North of the seaside hamlet of Lahinch is a simple southerly-dipping monocline. To the south of this is the broad downwarp of the central Clare syncline with its axis running north of Slieve Callan out to sea in Mal Bay. Still further south is an anticlinal swell running ENE.-WSW. through south Clare. Superimposed on these broad structures is a frill of secondary folds with a maximum width of about one mile, and steepening southwards towards the River Shannon.

(2) The incipient metamorphism of the rocks which is shown by:

- (a) Conversion of the thin coal seams to anthracite (5 to 8% volatiles, even in the flat-lying beds south of Lahinch).
- (b) The induration of all sand and silt members of the succession by secondary silicification. In places there is also considerable segregation of silica along joint planes, slump breccias, etc.

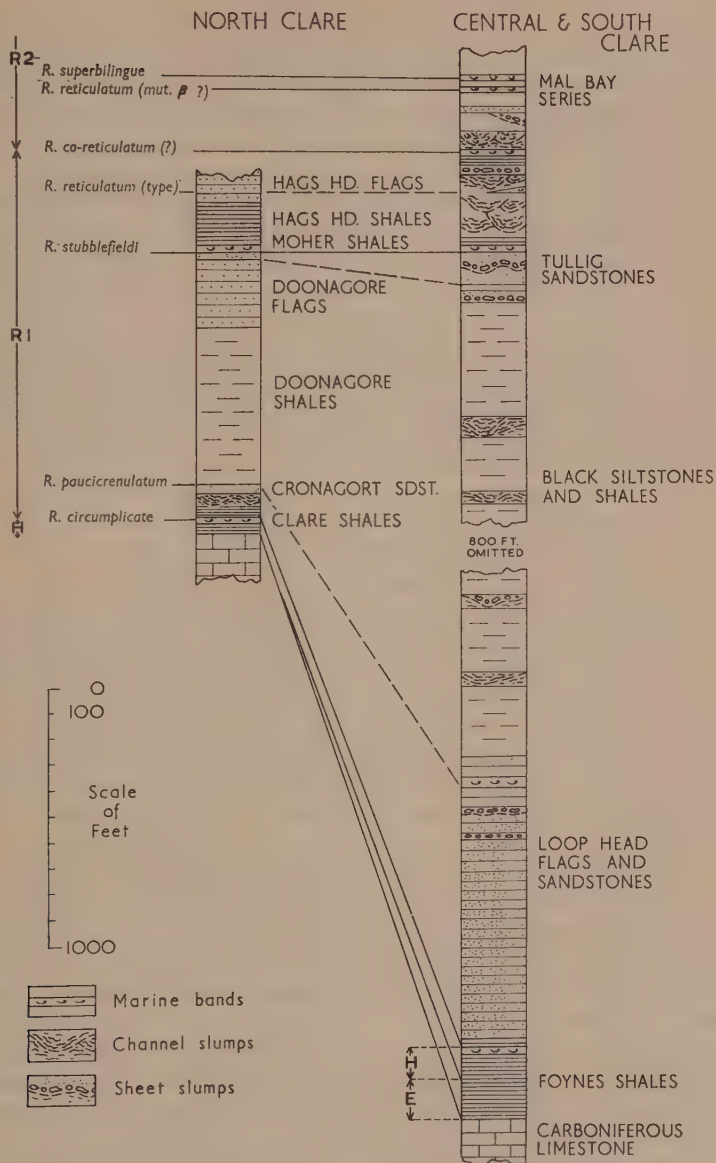


Fig. 2. Columnar Sections showing the Namurian succession of the West Clare Basin

Outline of the Geology of South Ireland (J. C. Brindley)

The last part of the meeting was devoted to a broad view of south Ireland, and since an outline of its general geology is already available (Smyth, 1939; Brindley, Gill & Mitchell, 1957) no more than a brief sketch is here necessary, further reference to particular features being embodied under the heading of daily itineraries.

The Old Red Sandstone of south Ireland is a typical continental deposit, with characteristic piedmont accumulations of coarse pebble conglomerate and an upper lagoonal phase represented by the plant-bearing Kiltorcan Sandstone series. A transition to shallow marine facies occurs in south Cork and Kerry and continues into the Carboniferous. These deposits represent, in the southern part of the country, a subsiding intermontane trough of general Caledonoid disposition: they exceed 10,000 feet in thickness in the central parts, thinning out rapidly eastwards over the Lower Palaeozoic massif of Leinster to less than 1500 feet at Hook, and disappearing entirely in south-east Wexford (Capewell, 1956). The Carboniferous rocks are chiefly bedded limestones—Tournaisian and Visean in age—often with a shaly basal member: reef limestones are prominent at many places and Visean volcanics occur, notably in Limerick.

Structurally the region belongs to the outer part of the Hercynian orogenic belt. In its northern portion, the pattern of broad flat-backed uplifts exposing Lower Palaeozoic cores is much affected by major faulting, and the influence of Caledonian basement structure on the later tectonics is repeatedly evident. South of the Galtees range—in the fold belt proper—the structure is one of long east-west anticlinal ridges swinging in broad arcuate fashion across the country. With increasing thickness of the cover, basement rocks are no longer generally exposed in these, and the parallel hill ranges comprise a succession of broad compound anticlines of Old Red Sandstone with narrow steep-sided synclinal troughs of Carboniferous between. Cleavage structures are strongly developed in this belt.

To the east this region abuts the Caledonian massif of east Leinster—apparently a stable block during succeeding orogenesis. It comprises a tract of old crushed and phyllonitic gneisses of pre-Cambrian age at the extreme south-east corner. The greywacke, slate and quartzite rocks of the Bray Series, usually treated as Cambrian, form two main tracts in east Wicklow and Wexford. While the Lower Palaeozoic rocks in the cores of the Hercynian anticlinal ranges are generally of Silurian slate and greywacke lithology, those of the main Leinster massif—excepting possibly the greywacke tract of Kildare on the west side of the granite mountains—belong to the Ordovician. They include the Ribband Series, locally with Arenig faunas, together with widely developed Caradocian (and perhaps younger) volcanics, the latter associated with local limestone developments in addition to the common graptolitic slate facies.

In eastern Ireland the succeeding Caledonian orogeny is dated roughly to within the range Upper Silurian–Middle Devonian. Its main phase was succeeded by intrusion of basic igneous masses, the various dioritic bodies of south-east Leinster, and a series of granites. The latter include the main Leinster batholith together with a large number of minor granite and quartz-porphyry sheets which more or less correspond to the distribution of the volcanic belts. In the case of the Leinster Granite itself, regional and intrusive movements were evidently closely associated and their relations indicate an extended structural history of the region (Brindley, 1957).

DAILY ITINERARIES

The National Grid references for Ireland quoted below give positions correct to one kilometre. The grid is printed on the new editions of the Half-Inch sheets of the Irish Ordnance Survey, which are the standard small-scale maps in Ireland. Sheets 14 and 17 cover the West Clare area.

Thursday, 29 August

Directors: Prof. W. D. Gill and Dr. F. Hodson

The party journeyed by coach from Dublin, and, south of Galway, were joined by the President of Section C of the British Association, Dr. G. H. Mitchell and Mrs. Mitchell. The party stopped at the top of the Corkscrew Hill south of Ballyvaughan to admire the amphitheatre in karst scenery which had been traversed from Galway Bay. Southwards the bare limestone scenery quickly gave way to the green rushy slopes underlain by Clare Shales. At Lisdoonvarna (R.14.98), Dr. Hodson took the party to see the basal Clare Shales and the contact with the underlying limestone at St. Brendan's Well, about a mile east of Lisdoonvarna. Here, the undulating limestone surface is overlain by a thin (two to four inches) bed of pebbly phosphate. Richly fossiliferous bullions from Dr. Hodson's faunal bands C and G provided good collecting. The party then proceeded to the excellent artificial sections in Clare Shales on both banks of the River Aille at the 'Phosphate Mine', Roadford (R.08.98). Here Dr. Hodson was able to demonstrate his faunal bands A to G and there was an opportunity to collect from almost the entire succession in solid goniatites. The basal phosphorite, here three feet thick, is well exposed in the right bank of the river and above it are the *H. beyrichianum* Bands A and B. The fossils at this level are difficult to extract and sometimes indifferently preserved. About 350 yards upstream, in the left bank, is a cliff section with rich bullions in faunal bands C and D. The goniatites here, particularly *Hudsonoceras proteum*, are beautifully preserved.

Friday, 30 August

Director: Prof. W. D. Gill

From Lisdoonvarna the party proceeded to Fisherstreet Bay (R.06.96). After ascending the scarp slope of the Clare Shales from the mouth of the River Aille, the route lay southwards along a cart-track running parallel to the cliffs towards the Cliffs of Moher. About 500 yards past the isolated farmstead, a deep narrow cove cuts about 100 yards inland. Beyond this is a wide platform of bare rocks. Here the main southern sheared margin of a slump channel complex was seen dipping 30° – 40° NNE. The Fisherstreet Bay channel slumps are developed in the sandy beds at the top of the Clare Shales, and their eroded tops are succeeded by undisturbed sandy alternations mapped by Dr. Hodson as the Gronagort Sandstone (see Plate 3, A). The complex channels, about 1000 feet wide and sixty feet deep, are bounded by shear planes like that figured in Plate 3, B, striking ESE. The deformation of the rocks within the channels consists of recumbent folds with axial plane cleavage incipiently developed. These folds seem to be confined to the margins of the channels and are due to lateral flowage from the channel. With reference to the main movement of the mass in the channel they are mostly folds in *a*. In parts of the channel less severely folded are deep movement grooves, and at some levels a complex fabric of small-scale frills trending obliquely to the direction of movement.

All these features were demonstrated in the good exposures on either side of the deep cove. On the north side of the cove the shear planes are dipping southwards, and overlying the planed-off top of the slump at this point is an abundant display of sand volcanoes up to three feet in diameter. Many members of the party were able to collect transportable specimens. About half a mile further north of this point, a spectacular development of recumbent folds was examined.

Rejoining the coach the party ascended the escarpment to the viewpoint at the top of the Cliffs of Moher near O'Brien's Tower (R.04.93). Here about 700 feet of rocks below the *R. stubblefieldi* Marine Band can be seen in the cliff, with only two thin slumped horizons. The marine band at this locality yields occasional solid specimens weathered from the thin limestone at its base. Squashed specimens occur over three to four feet of shale. The *R. stubblefieldi* Band is the most widespread and most frequently exposed marine horizon in Central and South Clare, and is a critical level for elucidating the stratigraphy and structure.

Southwards to Lahinch the road runs down a long composite dip-slope about the horizon of the Moher Shales. About five and a half miles south of Lahinch a minor road turns off sharply to Freagh Castle. There are three slump sheets forming Freagh Point (R.03.82). The lowest sheet, at the southern edge of the rock platform, is about fifteen feet thick and is com-

posed of rafts and blocks with sheared margins. The top is planed off by erosion and is overlain by a bed of sand up to three feet thick on which are about twenty sand volcanoes. Above this horizon, and forming the main rocky point, is a sheet about twelve feet thick composed of rolls and balls of fine flaggy sandstone. On top of the slump is a bed up to three feet thick of fine sandstone which is entirely composed of the coalescing flanks of sand volcanoes which can be examined in all states of 'dissection' (see Plate 3, C). Over 200 vents can be seen at the surface of the sandstone bed.

The next stop was at Spanish Point (R.03.78). On the foreshore near the end of the minor road to the point itself, the marine band with *R. co-reticulatum* (?) was examined. Some 300 feet below this horizon is the slump sheet, 150 to 200 feet thick, forming the point. This sheet was seen to be a chaotic complex of channel-form slumps with sheared margins, and the slump fabrics vary from tilted undeformed blocks up to fifteen feet across in a churned-up matrix, to balled-up masses of sandstone. The complexity of deformation decreases towards the top of the sheet and there is evidence of channel filling and renewed movement and settling during the deposition of some thirty feet of strata before undisturbed sedimentation began. Remarkable faulted 'graben' and ridge structures were seen in current-bedded sandstones near the top of the slump.

The party then walked southwards along the cliff to the rocks forming the north side of the inner bay, beneath the ruins of the former Atlantic Hotel. Here are fine exposures of a slump sheet composed of undistorted but variously tilted blocks up to six feet across of flaggy sandstone, which are floating in a churned-up muddy silt matrix. This matrix has assumed a 'schistosity' parallel to the margins of the blocks.

Moving round the bay, a stop was next made at the 'Black Rock' near the life-guard's hut, where there is load-casting of sand-filled ripple hollows into the clay below. A stop was made at the south-east corner of the bay near the house called Cassino Lodge. At the foot of the slipway is a marine band with *R. reticulatum* (mut B?) and, some 200 feet above, a further marine bed overlying a thin coal. Here good specimens of *R. superbilingue* were collected. At this point, deep brecciation, presumably by permafrost, descends some twenty feet down the cliff, breaking up the sandstone bands into disoriented blocks.

The final stop for the day was made at the village of Quilty (R.02.74). Opposite the Chapel, in the cliff, is an oblique section through a slump channel some fifteen feet deep, cut in black shales and silts, and filled with rolled-up masses of flaggy sandstone up to six feet across, many of them displaying well-preserved current-ripple casts. The Director demonstrated the evidence for large-scale load-casting in a three-foot bed of sandstone near the slump channel and suggested that the slumping might have been

connected with load-casting at this locality. The party then motored through to Kilkee.

Saturday, 31 August

Director: Prof. W. D. Gill

At the start of the day Dr. F. Hodson left the party, and was accorded a well-supported vote of thanks by the President.

The bus took the fine scenic coast road southwards from Kilkee, and after brief stops to see the rolling structure repeating the *R. stubblefieldi* Marine Band, a longer stop was made at Goleen Bay (Q.82.56). Here about 300 feet of beds are well exposed on a broad rock platform, and display a wide variety of slump structures. This locality is noteworthy for:

(1) Thin slumped sheets varying from six inches to three feet thick, in which the fabric consists of slabs about six inches across, all dipping 50° to 60° in what the Director considered to be the direction of movement. They seem to have been formed by a shearing, bull-dozing mechanism.

(2) A channel slump at least twenty feet deep in which one sheared margin can be followed for some 500 yards to a terminal 'snout'. This is one of the few three-dimensional exposures giving an indication as to the overall form of the channel type of slump.

(3) The largest sand volcanoes in Co. Clare occur on top of this channel slump. They are only eight to ten feet in height, but are up to thirty-five feet in diameter.

At the northern cliff margin of the deep cove at Goleen Bay, at the seaward end is a remarkable volcano, about fifteen feet across and eight feet high, which has slumped along arcuate shear planes into the substratum. Half the volcano has broken away along a joint to reveal in clear detail the structure of the vent and crater.

The party then proceeded to examine, in a dense drizzle, a series of slump sheets and sand volcanoes near the Natural Bridges of Ross, on the Loop Peninsula (Q.74.50). The main slump sheet in this area, which exposes rocks not far from the horizon of the Fisherstreet Bay slump seen on the first day, is a sheet about twenty feet thick extending on fairly constant thickness for several miles in the cliffs. For the greater part it consists of a thin layer of balled-up sandstone at the top and at the base, enclosing black siltstones and silty shales which a detailed examination shows to be intensely sheared. At least two large isolated blocks of sandstone are seen like two tectonic 'fish' in the middle of the siltstone in one locality. On the west side of the mouth of the deep cove which reaches the road, the party saw large masses of balled-up sandstone, still preserving a semblance of inter-stratification with grey siltstones, invading the main black siltstone and breaking it up into complicated rafts. At one point the

invading mass seems to have torn up the beds of sandstone at the base of the slump by a bull-dozing action, giving evidence of the direction of movement.

Amongst a large array of sand volcanoes often beautifully preserved, the novel feature was the occurrence of 'dribble-cones', in which in contrast to the smooth, runnelled flanks of the 'cinder-cone' type of structure, the outer flanks showed finger-like flows of what must have been viscous muddy silt.

On arrival back in Kilkee the weather greatly improved and there was time to examine the rocks round Moore Bay (Q.89.60).

On the north side of the Bay, the party examined the *R. stubblefieldi* Marine Band where the stream enters the Bay in its north-east corner. About 300 yards past the bathing place, good three-dimensional exposures were demonstrated of cylindrical slump folds which are clearly folds in *b*. Below this horizon, at the top of the highest cliff, large-scale 'rafting' of about twenty feet of flagstone overlying twenty feet of shales was seen. Brecciated shale rises at least fifteen feet between the rafts, one of which, about thirty feet across, shows fluting and moulding at its edges.

Finally, on the south side of Moore Bay thin balled-up sandstone sheets at the 'amphitheatre' were closely examined, and their origin much debated. At the Diamond Rocks, the thick rafted sheet which had been seen across the bay was again examined. In the sandstone Dr. Gwyn Thomas drew attention to remarkable cylindrical structures up to three feet across, which seemed to be continuous through many feet of rock, and which clearly involved a doming of the sand layers. Dr. Gwyn Thomas suggested that they had been formed by rising springs of water which had failed to break the stratification, but which had the same origin as the springs which had elsewhere formed sand volcanoes. In the steep cliff could be seen mounds of brecciated siltstone and shale, at least 100 feet across at the base. They were presumably indicating incipient rafting, but as the top of the sandstone was not broken, the space problem seemed difficult of solution. The President's exploits on the cliffs in search of contact evidence revealed his remarkable agility and iron nerve.

Sunday, 1 September

Director: Prof. J. C. Brindley

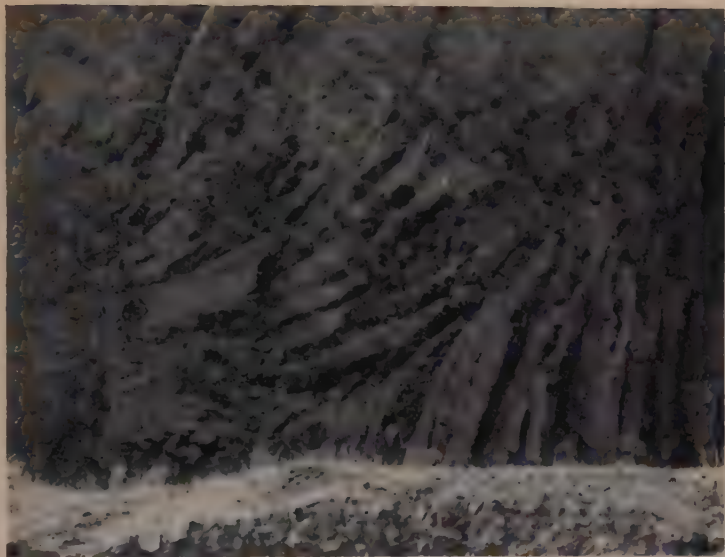
The greater part of this day was taken up by the coach journey from Ennis to Waterford. After traversing monotonous limestone country to cross the Shannon at Limerick a series of short detours from the main Tipperary road enabled significant features of the north-eastern end of the Lower Carboniferous volcanic basin just south of the town to be examined. The volcanic rocks here form a broad east-west trending syncline some six by twelve miles across, with minor outlying traces on all sides. Around the

margins hard igneous rocks stand out conspicuously in the landscape as steep escarpments, with more gentle inwardly inclined dip-slopes, and the effects of numerous cross-faults are easily discerned. The Carboniferous sediments range from K to D₂ in age with the volcanics forming a Lower and an Upper Group—early S₁ and early D₁ respectively (Ashby, in Smyth, 1939). Middle Carboniferous shales and sandstones occur in the centre of the basin. The rocks of the Lower Group are lavas and pyroclastics constituting a graded series of olivine-basalts, trachy-basalts, trachy-andesites, and trachytes: trachytic vent plugs. Sills attributed to this phase occur at a number of points. Picrite-basalts and analcite-bearing basalts are present in the Upper Volcanic Group, and lavas, tuffs, sills and vent agglomerates are known.

Immediately north of Caherconlish village (R.68.49) a field quarry exposes a flat-lying columnar sill of trachyte (see pl. III, *Mem. geol. Surv.*, 1907)—a pinkish rock with conspicuous potash felspar phenocrysts set in a drab, much-altered, trachytic groundmass. Quirke's Quarry, approximately a mile south-west of the village, was next visited to examine tuffs of the Lower Volcanic Group. The material here is composed of dark basaltic lapilli, sometimes vesicular, in a calcitic cement, and carries notable ejected fragments of both Old Red Sandstone and Carboniferous Limestone.

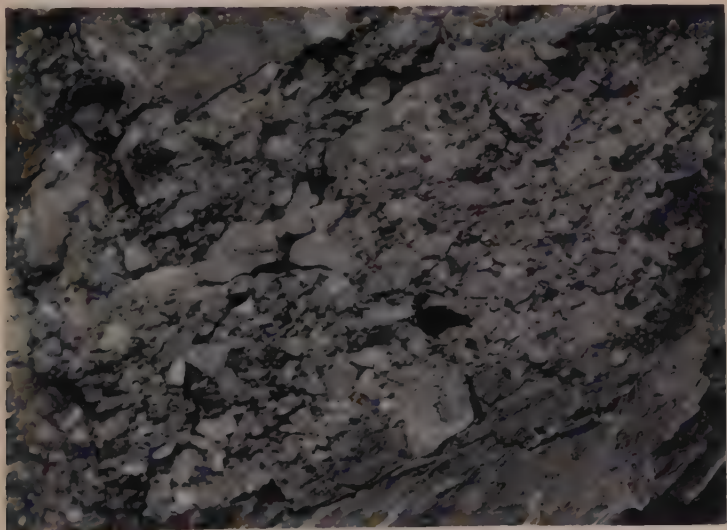
A subsequent halt at Grange quarry (R.71.50), close to the main road, revealed *Fenestrellina* Reef Limestones belonging to the C zone which underlie the volcanic groups—pale grey massive rocks, locally somewhat dolomitic. Fossils obtained here, though unusually scarce, included the characteristic *Fenestrellina*, together with brachiopods, trilobites, and various other typical Waulsortian forms. Linfield quarry (R.75.47), higher up on the main escarpment to the south-west, is situated in a thick sheet of columnar basalt, considered to represent a sill (Plate 4, A). A striking feature is the divergent arrangement of the columns around a large enclosed raft of tuff, and the manner of their development caused much discussion. Coatings of well-formed analcite crystals are present in slaggy portions of the rock—a feature of some significance since in its occurrence at various other localities in the Upper Basalts this mineral has been attributed to a primary origin. Dark grey inter-volcanic limestones (later S₁ to basal D₁) were examined in a quarry at Nicker village, with exposures of weathered basalt higher up the hill.

Excellent weather revealed a general view of much of southern Ireland and lunch was taken hereabouts. Across the low limestone country the various Old Red Sandstone anticlines, exposing Lower Palaeozoic sediments in their cores, appear as widely spaced hill ranges. To the north, beyond the Shannon estuary, the broad uplift of the Slieve Bernagh and Arra Mountains is breached in remarkable fashion by the river valley, and



(Photo by Dr. Hanrahan)

A. Linfield Sill, Upper Basalt, Limerick. Quarry face about 30 feet high



B. Coarse acid pyroclastics interbedded with black slates (Caradocian Volcanic Series). Coastal cliff near the Metal Man, Tramore, Co. Waterford

[To face p. 254]

east of this lies the similar structure forming the Silvermines and Slieve Felim ranges. In the south the long east-west folds—sharply faulted along their northern flanks—of Slievenamuck and the Galtees mark an approach to the Hercynian fold belt proper, and more distantly in the east the Slievenamon range is a prominent feature.

The route now lay through the fertile agricultural lowlands—the Golden Vein—via Tipperary to Cashel, where a visit was paid to the celebrated ruins on the 'Rock'. The ecclesiastical remains here include an Early Christian Round Tower (*circa* ninth century), the beautiful Hiberno-Romanesque church known as Cormac's Chapel (built A.D. 1134), and a more ruinous thirteenth-century cathedral. The group is sited atop a prominent crag of thick-bedded limestone—a minor box-fold such as commonly complicates the broad regional structure of the Lower Carboniferous rocks. At a quarry close to Rathkeevin (S.15.25) Carboniferous reef limestones with varied lithology show a well-defined primary sedimentary structure and abound in fossils, notable among which are *Lithostrotion*. They were described by Prof. Gill and a discussion on the origin of the distinctive tufa material here took place.

The route now lay via Clonmel and Carrick in the broad open valley of the River Suir—a major east-west stream of the region which follows the Carboniferous syncline between the Slievenamon ranges and the Comeraghs as a result of diversion of the original north-south consequent drainage. It is an area well known in geomorphology by the writing of Jukes on river development nearly a century ago and more recently studied by Miller (Miller, 1939). From Granny Castle (S.57.14) (Z zone) southwards the succession of Lower Carboniferous and Old Red Sandstone formations on the north flank of the Comeraghs anticline can be followed in the valley to Waterford, where the coarse conglomerate beds at the base of the latter lie with gentle dips on an eroded surface of isoclinally folded Ordovician slates and lavas. The unconformity here is excellently displayed on a large scale and was examined on a subsequent day.

Monday, 2 September

Director: Dr. G. J. Murphy

An almost continuous section of the Ordovician rocks—chiefly volcanics of early Caradoc age—is afforded by the fine crenulate cliff line of the south Waterford coast. It extends westwards for a distance of more than twelve miles from Tramore Bay, where the geology has recently been studied by Dr. G. J. Murphy (Murphy, 1957), to Ballyvoyle Head where the Old Red Sandstone unconformity delimits the Lower Palaeozoic massif. The lowest member of the succession—the apparently unfossiliferous Tramore Shales—is suggested to be of Arenig age, and is overlain unconformably by the

Tramore Limestone group. This comprises dark calcareous shales with minor impure limestone beds and carries a varied brachiopod-trilobite fauna of *gracilis* age showing strong Baltic-American affinities. A large thickness of rocks—chiefly acid lavas and pyroclastics—follows conformably on the limestone group. The felsitic lavas include fluidal, nodular and perlitic types: keratophyres, pillow-lavas, and basic tuffs also occur more locally, and many dolerite sills—the largest over 200 feet thick—are present. Graptolitic shales of the *multidens* Zone are intercalated with the volcanic rocks. Steep westerly dips characterise the strike section in Trimore Bay but further on, in the strongly folded volcanics, it would appear that the general inclination is moderate and the characteristic *Monticulipora*-bearing limestones appear repeatedly as far westward as Dunbrattin Head.

The section commences immediately beneath Trimore town (S.58.01), where a visit to the dark, much-deformed Trimore Shales was deferred until later in the day because of tidal conditions. On the outskirts of the town a footpath leads to Doneraile Cove where graptolitic shales, appearing in the lower part of the volcanic series above the limestone, are of *gracilis-peltifer* age. Dark calcareous shales with bands of impure nodular limestone typical of the Trimore Limestone Series were examined at Newtown Cove (X.57.99) and in the small roadside section immediately above, while just around the road bend a small quarry lies in one of the dolerite sills. The purer beds of limestone abound in well-preserved colonies of the stromatoporoid *Monticulipora petropolitana* and shaly beds are crammed with fragmentary bryozoan, brachiopod and trilobite remains, from which a large fauna has been described (Reed, 1899).

In the cliffs close to the Metal Man (Plate 4, B) coarse acid pyroclastics and inter-bedded black shales, higher in the volcanic series, were examined, and further west a well-defined pillow-lava horizon is to be seen—here unfortunately inaccessible—in the cliffs below. Continuing westwards, a halt at Garrarus Strand (X.55.98) provided a typical display of the volcanic rocks—acid pyroclastics in places extremely coarse and agglomeratic, felsites with local fine flow banding, and other types—associated locally with black shales. A group of felsite sheet intrusions was seen immediately to the left of the entrance to the beach, one of them pinching out bluntly in a remarkable manner. Here also a small vesicular keratophyre flow shows evidence of pillow structure in its basal parts.

A drive over the coastal platform (approximately 250 feet O.D.) via Annewtown and Bunmahon illustrated typical south coast scenery—a rugged cliff line broken here and there by the drowned valley mouths and incised river channels. Shatter belts—trending roughly east-west—in the coastal rocks mark the effects of Hercynian deformation on the basement, and in the picturesque inlet of Ballydouane Bay (X.41.98) fault-bounded

blocks of the Old Red Sandstone cover remain, in places tilted to a vertical attitude. In the basal portion of this formation a change in the pebble content was strongly in evidence, from the usual vein-quartz assemblage to a mixture of volcanic fragments from the Lower Palaeozoics beneath. Enythrite was discovered here by members of the party, evidently representing a small offshoot of the Bunmahon mineralisation. In returning, the once-important copper-mining centre at the latter village was noticed and a short halt by a roadside tip produced typical material—chalcopyrite in vein quartz—from the lodes which run in a north-westerly direction in the Ordovician rocks.

Tuesday, 3 September

Director: Prof. J. C. Brindley

The party travelled via New Ross to the Hook promontory on the eastern side of the drowned estuary of Waterford harbour. Here the morning was occupied with an examination of the Upper Palaeozoic succession exposed continuously in the gentle southerly dipping beds of the low cliffs on either side of the headland. The Old Red Sandstone is made up of the usual coarse red sandstones and conglomerates in the lower parts, with yellow sandstones above, in turn succeeded by the passage beds to the Carboniferous marking the change from continental to marine conditions. The Carboniferous succession—1300 feet in all—is subdivided by Smyth (Smyth, 1939) as follows:

<i>Chonetes</i> Beds and <i>Linoproductus</i> Beds	...	...	...	...	C ₂
Dolomite and Supra-Dolomite Beds	...	...	...	...	C ₁
<i>Michelinia favosa</i> Beds	...	...	...	...	Z ₁ , Z ₂
Fish Shales	...	...	...	...	K ₂
Grey Sandstone Group	...	...	...	...	K ₁
Transition Beds					
Upper Old Red Sandstone					

The first stop, at Lumsdin's Bay (S.75.01) was to examine the lower part of the succession. Well-bedded dark limestones with shale partings representing the *Michelinia favosa* Beds form a low tidal platform: they are crowded with well-preserved brachiopods and corals, amongst which the typical form as well as *Zaphrentis* and many others were collected. After traversing the soft Fish Shales—responsible for the coastal inlet and scarcely exposed beneath the sandy beach—the party moved on to the bedded grey sandstones and transition beds which locally carry phosphatic nodules and poorly preserved brachiopods. Ripple marking and current-bedding here indicate shallow-water conditions and the 'Furoid' bed, some six feet thick and crowded with typical *Chondrites* remains, is commonly taken as the base of the Carboniferous, since the first marine fossils appear

immediately above it. Below are the red and yellow current-bedded sandstones and shales of the Old Red Sandstone.

Lunch was taken on the cliffs at the Hook lighthouse (X.73.97) where, in clayey even-bedded limestones of the Supra-Dolomite and *Chonetes* Beds, fossils occur in great profusion. Bryozoan colonies, intact echinoderms and brachiopods with perfectly displayed internal anatomy were inspected, which are here beautifully revealed by the weathering off of the soft shaly surroundings. The fine crinoids and echinoids for which the locality has long been famous are, unfortunately, no longer common, but none-the-less *Maccoya* and other characteristic forms were obtained by various members of the party.

In the afternoon the crystalline rocks—biotite and hornblende-gneisses, locally migmatitic—which form the south-eastern part of County Wexford were examined. They may be regarded as pre-Cambrian in age (Baker, 1953) and correspond to the old crystalline massifs of Pembrokeshire, Llyn and Anglesey on the opposite side in Wales. In fact, it has been suggested that a general geanticlinal tract of pre-Cambrian character occupies the Irish Sea area. A walk over the low coastal outcrops from Rosslare Harbour (T.14.13) to St. Helen's showed these old crushed amphibolitic gneisses with occasional pegmatite striping and a few later dolerite dykes. Cataclastic features are dominant and at Greenore Point the rocks are essentially low-grade chlorite-schists. Local less-altered agmatic developments are seen at St. Helen's Bay, and in the quarry nearby, where the party rejoined the bus, typical orthogneisses were collected.

Along this section continuous, much-slipped cliffs in the older boulder clay deposits of the first main—or Eastern General—glaciation show well its characteristics, and inland the subdued topography of the drift-covered plain is typical. It is a uniform warm brown-coloured clay, low in pebble content, but with conspicuous erratics of Cretaceous flint. Some large boulders of the Carnsore granite were noticed hereabouts—a distinctive homogeneous biotite granite crowded with large pink potash-felspar phenocrysts—which occurs in the crystalline tract a few miles further south.

Outcrops of the unconformably-overlying Ordovician sediments immediately south of Rosslare Harbour were unfortunately hidden by sand and tide at the time of visit, but corresponding rocks appear a few miles inland at Tagoat. In this region, coarse clastic types occur in the series, in contrast to the muddy and carbonate facies typical at Tramore—a feature evidently in relation to a stable pre-Cambrian land-mass in the east, whose influence is seen throughout the geological history of the region. Thus, of the Upper Palaeozoic rocks, the Old Red Sandstone thins rapidly eastwards from its maximum of well over 10,000 feet in the Comeragh Mountains (Capewell, 1956) to less than 1500 feet at Hook promontory, and

disappears entirely around Wexford town, where a shallow-water, locally conglomeratic facies of the Lower Carboniferous rests directly on the older rocks. On the return journey, highly sheared and pink-stained quartzites at the north-eastern end of the Bray Series tract of the Forth Hills were seen in a roadside quarry at Kerlogue (T.05.19) outside Wexford town. In the low ground a few hundred yards to the south of this, old quarries expose the immediately adjacent Carboniferous Limestone—here dolomitic and with local current-bedding—apparently of a shallow-water facies.

Wednesday, 4 September

Director: Prof. J. C. Brindley

The final day's route lay northwards to Dublin across the Lower Palaeozoic and Bray Series rocks of the counties Wexford and Wicklow. Inland, much of southern Wexford is formed by the coastal peneplain, a conspicuous high platform at 200 feet to 300 feet O.D., across which excellent views of the geology of the region can be obtained. In the north-west the distant granite ranges of Brandon Mountain, the Blackstairs and Mount Leinster—broken through by the gorges of the rivers Barrow and Nore—form the southern end of the large Leinster batholith. It extends from the outskirts of Dublin to disappear finally beneath the Upper Palaeozoic cover marked by the prominent Old Red Sandstone escarpment of County Carlow. Lower Palaeozoic slates form the platform nearer at hand among which the thick volcanic series from Tramore extends north-eastwards to reach the coast between Arklow and Ballymoney. The Ribband Series which flanks this broad belt has yielded Arenig graptolites at some localities (Harper, 1948). Several prominent hill groups—Carrickbyrne, Carrickmastia, Camaross, Bree Hill and others—mark the occurrence of minor granitic bodies which coincide generally with this broad belt of volcanics. They are typically post-tectonic sheet-like intrusions of Caledonian age, and range from quartz-felsite to microgranite and granite.

A few miles north of Wexford at Curracloe (T.10.29), terminal deposits of the second general ice-sheet—the Midland General Glaciation of Weichsel age—were inspected. They form high ground in a characteristically stony boulder clay, which is scattered with numerous kettle holes and forms a strikingly youthful morainic topography in contrast to the subdued relief of the older drift country to the south. At Ballaghkeen quarry (T.07.38) some two miles west of the main Arklow road, contact features of the minor granite of Ballinaghmuddagh were seen. It is a uniform biotite-granite which develops biotitic hornfelses in the adjacent Lower Palaeozoic sediments: the contact rocks here show earlier (pre-crystalline) minor folds with vertical pitch. A little diffuse migmatitisation and some intrusive brecciation are also present, and quartz-biotite-porphyry dykes are

prominent. After returning to the main road a quarry at Carriganeagh (T.16.57), two miles south of Gorey, showed typical pale flow-banded felsite of the volcanic belt much altered and silicified.

North of Gorey, on Ballymoney Strand (T.21.60) the Ballymoney Series represents the northern end of the Caradocian volcanic belt. It is a mixed series of sediments and volcanics, with black shales and local impure limestone horizons carrying graptolitic and shelly faunas respectively. Sedimentary features of the finer acid tuffs include graded bedding and sole features which caused some discussion while the coarser representatives are unsorted volcanic conglomerates of mixed character. The latter show erosion and channelling of the underlying sediments, and a volcanic mud-flow origin is suggested. Southwards along the coast the series passes over to fine alternations of red and yellow shale and silt, much cleaved and folded on steeply pitching axes. This is a feature which occurs widely in the region and may perhaps be attributed to subsequent compression effects which followed the main regional folding and caused slip and attenuation in a strikewise direction.

After Arklow the road runs in the picturesquely wooded and incised valley of the Avoca River, reaching the Avoca mining district (T.20.81) a few miles further on. This is a three-and-a-half-mile belt of hydrothermal sulphide impregnations, now exploited for copper, in the Palaeozoic slate and volcanic rocks. The ore bodies follow conformable, north-easterly-trending lenticular zones, with iron pyrites as the chief mineral, and lesser amounts of chalcopyrite, galena, blende and magnetite. More than three million tons of ore have been produced to date, with estimated reserves in excess of twelve million tons carrying just over one per cent copper. Ore deposition to some extent coincided with the regional movements, and the deposits are thus considered to be of Caledonian age.

Time was limited, however, as many members wished to attend the opening meeting of the British Association in Dublin later in the day, and after a momentary halt the journey was resumed via the scenically popular 'Meeting' of the Avonmore and Avonberg rivers. On ascending the valley side the roadside quarry at Ballinacarrig (T.18.86), two miles south of Rathdrum, was passed. It exposes granite and contact rocks of the small Caledonian mass of Ballinacash, the latter muscovite-rich andalusite-hornfels with extensive retrograde features. North of Rathdrum the road skirts a small lake flat (glacial Lake Glenealy) whose overflow eastwards through the bounding ridge of phyllite produced the well-known dry gap of Deputy's Pass. The minor road traversing this leads directly to the extensive road metal quarries of Carrigmore (T.25.89) in biotite-hornblende-diorite, one of the minor Caledonian basic intrusions. The visit to this point was, however, of necessity eliminated, owing to the need to press on to Dublin, and the remainder of the route lay mostly in the rolling coastal

portion of the Bray Series tract of east Wicklow, with the abrupt margin of the Calary Plateau (900–1000 feet O.D.) showing prominently to the west, and the rugged quartzite peaks of Carrick Mountain and the Sugarloafs as typical features in its topography.

ACKNOWLEDGMENTS

The authors are sincerely indebted to Dr. G. J. Murphy, who has kindly provided the information on which the itinerary for the Tramore region (2 September) is based, likewise to Dr. J. W. Baker, who has similarly assisted regarding the Rosslare rocks.

REFERENCES

- BAKER, J. W. 1955. Pre-Cambrian Rocks of Co. Wexford. *Geol. Mag.*, **92**, 63–8.
- BRINDLEY, J. C. 1957. The Aureole Rocks of the Leinster Granite in South Dublin, Ireland. *Proc. R. Irish Acad.*, **59B**, 1–18.
- , W. D. GILL & G. F. MITCHELL. 1957. 'Geology' in *A View of Ireland*, 15–39. British Association for the Advancement of Science, Dublin.
- CAPEWELL, J. G. 1956. The Stratigraphy, Structure and Sedimentation of the Old Red Sandstone of the Comeragh Mountains and adjacent areas, Co. Waterford. *Quart. J. geol. Soc. Lond.*, **112**, 393–410.
- GILL, W. D. & P. H. KUENEN. 1958. Sand volcanoes on slumps in the Carboniferous of County Clare, Ireland. *Quart. J. geol. Soc. Lond.*, **108**, 441–60.
- HARPER, J. C. 1948. The Ordovician and Silurian Rocks of Ireland. *Proc. Lpool geol. Soc.*, **20**, 48–67.
- HODSON, F. 1954a. The Beds above the Carboniferous Limestone in North-West Co. Clare, Eire. *Quart. J. geol. Soc. Lond.*, **109**, 259–83.
- . 1954b. The Carboniferous Rocks of Foynes Island, Co. Limerick. *Geol. Mag.*, **91**, 153–60.
- LAMPLUGH, G. W. *et al.* 1907. The Geology of the Country round Limerick. *Mem. geol. Surv. Ireland*, 119.
- MILLER, A. A. 1939. River Development in Southern Ireland. *Proc. R. Irish Acad.*, **45B**, 321–54.
- MURPHY, G. J. 1957. Summer Field Meeting in Ireland, programme for Monday, 2 September. Circular No. 593. Geologists' Association, London.
- REED, F. R. S. 1899. The Lower Palaeozoic Bedded Rocks of County Waterford. *Quart. J. geol. Soc. Lond.*, **55**, 718–71.
- SMYTH, L. B. *et al.* 1939. The Geology of South-East Ireland, together with parts of Limerick, Clare and Galway. *Proc. Geol. Ass., Lond.*, **50**, 287–351.
- TURNER, SELWYN J. 1952. The Lower Carboniferous Rocks of Ireland. *Lpool and Manchr. geol. J.*, **1**, 113–47.

Field Meetings in the Cretaceous of the Western Part of the Weald

Report by the Directors

Received 28 July 1958

FOR THE CENTENARY YEAR Field Meetings Programme, two Field Meetings were planned to demonstrate the variations of structure and geomorphology, and the nature of the Cretaceous beds, in different parts of the western portion of the Weald. The first Field Meeting consisted of a dip traverse across the area from the North to the South Downs, the second of a strike traverse along the foot of the North Downs.

WEST SURREY AND WEST SUSSEX

Saturday, 10 May 1958

Report by the Directors: J. W. Reeves and J. F. Kirkaldy

Despite the difficulties caused by the bus strike, the party assembled promptly at Charing Cross and proceeded by coach to Banstead Downs (250167).¹ A brief stop was made to note the pronounced northward slope of the bare chalk downland (a portion of the sub-Eocene erosion surface) on either side of the road. This contrasted markedly with the broad conifer- and heath-clad flats of Burgh, Banstead and Walton Heaths, which all form part of the 'Pliocene bevel' and are underlain by sand and shingle. At Pebblecombe the coach turned west to Box Hill (180152). Dr. Kirkaldy, in analysing the features of the extensive view, commented on the difference in the width of the outcrop of the Gault to the west and east of Dorking; on the persistent northward dip of the strata, the inclination being normally only a few degrees, though steepening considerably along local monoclinal flexures; and finally he drew attention to the marked change in the impressiveness of the escarpment of the Lower Greensand, as one followed it from Leith Hill through Glory Woods to the neighbourhood of Brockham. This decrease in height reflected the reduction in the resistant bands of chert and well-cemented sandstones in the Hythe Beds.

The coach then returned to Pebblecombe (213529), descended the Chalk scarp and crossed the feature formed here by the Upper Greensand. It was mentioned that so well marked a feature was not typical, for on the 'north crop' of the Weald, the Upper Greensand was usually both thinner and less well cemented than in Sussex. The coach turned westwards along A.25 and

¹ Grid references apply to the 100 Km. square 51 (TQ).

then southwards along the Dorking By-Pass. The position and nature of the various divisions of the Lower Greensand were indicated. The drive continued through Holmwood and Ockley to Rudgwick, across the wide and rather featureless outcrop of the Weald Clay. The marked incision of the streams was noted, when the Arun-Mole watershed had been crossed. A halt was made at the Rudgwick Clay Works (083341).

Mr. Reeves showed Ordnance Survey Sheets 182 and 183 (one inch to the mile) which had been hand-coloured to exhibit clearly the division of the Weald Clay into three groups (Reeves, 1958). The division was based on the fact that a series of red clay beds occurred towards the middle of the formation. The oldest and youngest of these had been traced westwards from the coast near Eastbourne and formed the boundaries of the three groups. The party was standing on the oldest. The mapping of these and other beds—mainly sandstones and Paludina Limestones—had shown a remarkable increase of thickness as the formation was traced to the north-west, from some 220 feet near Eastbourne to something like 1370 feet where the party stood. It was hoped that these lithological divisions could be linked to palaeontological ones and the party was urged to look for ostracods which seemed to offer a possible solution to this end. No ostracods were discovered in the clay pit, but some were found later in a newly dug main-drainage trench at Bucks Green (083328). These were from group I. The Director mentioned that the coloured maps had been deposited with the Association's Library and would be available to those interested, for further study. Lunch was taken at Bucks Green.

After lunch the drive continued through Billingshurst, Coolham and Thakeham to Jackets Hill (101163) on the north side of the Greenhurst Anticline. Dr. Kirkaldy first pointed out that the Greenhurst Anticline and the complementary Wiggentholt Syncline to the north were members of the system of *en echelon* folding which was one of the distinctive features of the 'south crop' of the Weald. Secondly that the Hythe Beds, excellently exposed in the road cutting, were of the 'ragstone' facies, another contrast with the north-western side of the Weald.

The next exposure to be visited was the sand-pit of the Marley Tile Co. in Chantry Lane, Storrington (093138). The party first climbed the tip-heaps to examine the 'Iron Grit' (Kirkaldy, 1935). For a distance of some sixteen miles, centred on Pulborough, the clean sands of the Folkestone Beds and the stiff clays of the Gault are separated by a few inches of intensely hard pebbly limonitic grit showing slight traces of bedding. In all other parts of the Weald, several feet of glauconitic sandy clays with seams of phosphatic nodules are developed at this level. The Iron Grit was interpreted as contemporaneous iron pan capping a submarine shoal. Mrs. C. B. Welch found a specimen of *Hoplites dentatus* (J. Sowerby) in the stiff clays overlying the Iron Grit. This is important, for it is the first fossil

record from this pit. The Director also drew attention to the 'White Flint Drift', which overlay the Gault. The hill-top into which the pit had been cut was part of the '200-foot Platform' (Kirkaldy & Bull, 1940, 119-22), which is much more extensively developed along the foot of the South Downs than on the northern side of the Weald. The party then descended into the pit to examine the Folkestone Beds, which were the usual clean quartzose sands. The brick-red coloration of parts of the sands was pointed out as another feature, frequently found in Sussex, but rare elsewhere in the Weald. Considerable interest was shown in the diamond-shaped pattern of slightly cemented layers in the sands. The party then drove eastwards through Steyning and Upper Beeding to Poynings for tea. After the President (Prof. D. Williams) had proposed the customary vote of thanks, the party drove to the Devil's Dyke Hotel (259111). Mr. Reeves pointed out the features of the extensive view and indicated the position of the test boring made for oil in 1937. The Pyecombe anticline had been selected because it was a closed one and lay between the oil indications of Lulworth Cove and the natural gas of Heathfield. Although the drill reached a depth of over 5000 feet, the only oil found was that which could be extracted from Kimmeridge Shales by chloroform. Such a method was considered to be financially unsound and the hole was abandoned. Dr. Kirkaldy contrasted the bare chalk downland of so much of the South Downs with the veneer of 'Clay with Flints' and 'Pliocene deposits', which the party had seen earlier in the day overlying the Chalk of the North Downs. He then led the party to the lip of the Devil's Dyke and discussed the various views (Bull, 1936; Fagg, 1954; and Sparks & Lewis, 1957), which had been put forward as to the origin of the Devil's Dyke and of other comparable steep-sided flat-bottomed curving valleys gouged into the Chalk escarpment.

No further stops were made during the return journey via Patcham and Cuckfield and across the outcrop of the Hastings Beds around Balcombe, to Redhill and London.

EAST SURREY AND WEST KENT

Saturday, 7 June 1958

Director: J. F. Kirkaldy

The party drove from Charing Cross to Newlands Corner (045492). Unfortunately visibility was so poor that St. Martha's Hill was only just visible. The Director said that the distinctive features of the immediate neighbourhood were firstly the belt of structural complication along the foot of the Downs, culminating westwards in the steep dips and strong faulting of the Hog's Back (Dines & Edmunds, 1929, 5-11) and secondly

the nature of the middle division (the Sandgate Beds) of the Lower Greensand. The party then drove to Albury and walked up Blackheath Lane (047475) to examine the Bargate Beds, calcareous sands and sandstones with a high proportion of derived oolitic grains. Fish teeth and derived Jurassic ammonites were not forthcoming on this occasion, though they have been found here in the past. The party walked through the woods to Warren Lane (054475), noting small exposures in the Folkestone Beds just by the edge of the wood at the top of the lane, to see the decalcified Bargate Beds (Kirkaldy, 1933, 275-85). The Hythe Beds were well exposed in the lower part of Warren Lane. They consisted of fine grained, slightly clayey, sands carrying appreciable amounts of glauconite. Thin beds of rubbly sandstone and chertified sandstone were also developed. The clean character of the Folkestone Beds, the strong wedge bedding in the Bargate Beds and the appreciable clay and silt content of the Hythe Beds were commented upon as significant features in this neighbourhood.

The party rejoined the coach, drove eastwards to Gomshall and then walked up Colekitchen Lane (084482) to the sunken footpath leading away eastwards. A few strokes of a trowel into the overgrown bank proved the presence of Gault Clay overlying the brownish sands of the Folkestone Beds. Less than fifty yards up Colekitchen Lane, at the top of the bank on the eastern side, a long section in white encrusted, slightly micaceous Upper Greensand was examined. The Director pointed out that the outcrop of the Gault was here demonstrably less than forty yards in width; in the next lane to the west, London Lane (074483), it was even narrower. Several wells, sited along the north edge of the North Downs and only a few miles away, had penetrated more than 250 feet of Gault (Aldershot 284 feet, Clandon 288 feet, Ashted 265 feet, etc.). Elsewhere in south-east England the Gault showed only gradual variation in thickness. He suggested that the belt of structural complication along the foot of the Hog's Back continued much further eastwards than was shown on the official maps. Owing to the large amount of downwash extending from the Downs well out on to the Lower Greensand, deep trenching would be necessary to work out this and other sections in detail.

After lunch at Abinger Hammer, the party drove eastwards to examine the section in the Folkestone Beds, with its fantastic development of swirling ironstone, at the western end of Westcott Heath (134484). The Director, after referring to the different interpretations of the structure of the area between the 'Nower', Dorking and Coast Hill in front of the party, that had been reached by Hayward (1932, 5-7) and Dines & Edmunds (1933, 9-12), stated that work in progress was producing another and more complex picture of the structure of the belt of country between Dorking and Albury.

The party then drove, without alighting, towards Nutfield. Attention was

drawn *en route* to the marked widening to the east of Dorking of the outcrops of the Gault and the Folkestone Beds. There was no evidence that this was due to sudden change in thickness. It was also pointed out that in the neighbourhood of Dorking, the Bargate Beds passed laterally into a thin development of glauconitic loams (the Sandgate Beds). The low relief of the outcrop of the Hythe Beds, between Dorking and Reigate, was due to the absence of stone bands. At Redhill, the road ascended the prominent feature formed by the Hythe Beds, containing developments of hard sandstone, and the overlying Sandgate Beds. At Nutfield the party visited the new 'Priory' pit of the Fuller's Earth Union (291154). After the Director had spoken of the sudden swelling of the Sandgate Beds, due mainly to the incoming of thick seams of Fuller's Earth (see Dines & Edmunds, 1933, 63), the party examined the fine section. Three seams of Fuller's Earth were present, the lowest one sixteen feet in thickness, separated by loamy glauconitic sands and thick beds of sandy limestone. Some nodules of barytes were found, but they were stated by the guide to be much less common than in the older pits on the north side of the main road.

After tea at Nutfield, the President (Prof. D. Williams) proposed the customary vote of thanks, and the party then drove to the car park on Tilburstow Hill (349501). After studying the extensive view and noting the abundant chert fragments lying on the crest of the scarp of the Lower Greensand, the party descended the scarp and walked along the footpath to the pit showing chert beds dipping northwards at 45° . The Director pointed out that the party was standing on the most easterly of a number of outliers of Lower Greensand, occurring well below the level of the corresponding beds on the main scarp. Such anomalous occurrences must be due either to faulting or to landslipping. The Geological Survey had favoured faulting (Dines & Edmunds, 1933, 13-15); but the Director was convinced that the geometry of these outliers could only be explained by the landslipping hypothesis of F. Gossling & A. J. Bull. One most significant point was that along the main scarp, the Hythe Beds were demonstrably underlain by the Atherfield Clay. Both at Bower Hill (Gossling, 1935, fig. 46, 366) and at Tilburstow Hill (Gossling & Bull, 1948, fig. 14, 137) along the southern margin of the landslipped mass, the Hythe Beds spilled across the outcrop of the Atherfield Clay to rest on Weald Clay. The party then walked round the footpath, noting the high dips and local succession in the Hythe Beds, and returned up the deeply sunken road. The dips of 40° visible in exposures, high up in the road banks (353499) opposite the drive to Brakey Hill, contrasted markedly with the dip of 6° which could be seen in undisturbed beds at the top of the eastern side of the cutting, about one hundred yards further north.

The journey then continued through Godstone and Westerham to the disused roadstone quarries of the Kent County Council at Dryhill (497553).

The Hythe Beds had now changed from their arenaceous development in West Surrey into a succession of chert-bearing beds overlying alternations of hard sandy limestone ('Kentish Rag') and loamy glauconitic sand ('hassock'). The Director stated that this 'rag and hassock' facies continued eastwards throughout Kent. As always, the main interest of this exposure was the unexpectedly strong folding of the beds. It was pointed out that many such sharp folds of limited lateral extent were traceable to the south of the valley of the River Darent from near Limpsfield to beyond Sevenoaks. They seemed to be as much a local phenomenon as were the land-slipped outliers to the west of Godstone.

The party then drove up Polhill, to the west of which the Upper Greensand passes laterally eastwards into the highest beds of the Gault, and then through Bromley to London.

REFERENCES

- BULL, A. J. 1936. Studies in the Geomorphology of the South Downs. *Proc. Geol. Ass., Lond.*, **47**, 99-129.
- DINES, H. G. & F. H. EDMUNDS. 1929. The Geology of the Country around Aldershot and Guildford. *Mem. geol. Surv. U.K.*
- . 1933. The Geology of the Country around Reigate and Dorking. *Mem. geol. Surv. U.K.*
- FAGG, C. C. 1954. The Coombes and Embayments of the Chalk Escarpment. *Proc. Croydon nat. Hist. Sci. Soc.*, **12**, 117-31.
- GOSSLING, F. 1935. The Structure of Bower Hill, Nutfield (Surrey). *Proc. Geol. Ass., Lond.*, **46**, 360-90.
- & A. J. BULL. 1948. The Structure of Tilburstow Hill, Surrey. *Proc. Geol. Ass., Lond.*, **59**, 131-9.
- HAYWARD, H. A. 1932. The Geology of the Lower Greensand in the Dorking-Leith Hill District, Surrey. *Proc. Geol. Ass., Lond.*, **43**, 1-31.
- KIRKALDY, J. F. 1933. The Sandgate Beds of the Western Weald. *Proc. Geol. Ass., Lond.*, **44**, 270-311.
- . 1935. The Base of the Gault in Sussex. *Quart. J. geol. Soc. Lond.*, **91**, 519-37.
- & A. J. BULL. 1940. The Geomorphology of the Rivers of the Southern Weald. *Proc. Geol. Ass., Lond.*, **51**, 115-50.
- REEVES, J. W. 1948. Surface Problems in the Search for Oil in Sussex. *Proc. Geol. Ass., Lond.*, **59**, 234-69.
- . 1958. Subdivision of the Weald Clay in Sussex. *Proc. Geol. Ass., Lond.*, **69**, 1-16.
- SPARKS, B. W. & W. V. LEWIS. 1957. Escarpment Dry Valleys near Pegsdon, Hertfordshire. *Proc. Geol. Ass., Lond.*, **68**, 26-38.

WRITTEN CONTRIBUTIONS TO THE DISCUSSION OF A PAPER PREVIOUSLY TAKEN AS READ

The Editor,

Dear Sir,

In their account of Glacial Deposits around Hertford (*Proc. Geol. Ass., Lond.*, 69, 103) Dr. Clayton and Miss Brown make out a satisfying and useful case for the existence of a Lake Hertford impounded by an ice-front somewhere east of Ware. However, the full implications of their views on the origin of the Lower Lea (p. 115, para. (a), seem to have been passed over. To judge by the text, the term *Lower Lea* appears to mean the river from Ware southwards. Now the map (fig. 2) implies contrasted origins for the two reaches into which this part of the Lea can be divided. From Ware to the line of the reconstructed divide on the south-east side of the Finchley Depression, the river has developed across, and has incised itself into, the fill of Lake Hertford. Beyond the line of the divide, some other mode of origin must be envisaged. I should like to ask the authors if they have considered the possible location of a spillway for Lake Hertford on the line of the Lower Lea.

Spillways necessarily operated when the lake was present. Obvious possible sites are at the heads of the two arms, near Watford and Finchley. But the relationship between the Colne and the Lea in the Vale of St. Albans, and the presence of end-moraine at Finchley, fail to suggest any vigorous downcutting by effluent streams. The Lea, on the other hand, has been as successful in extending itself across the site of the lake as has the Warwickshire Avon in lengthening its course across the former site of Lake Harrison.

One must suppose that some kind of depression existed south of the Middlesex loopway—a depression large enough to receive the Thames at the last main diversion. Such a depression can scarcely have lacked surface drainage, and the divide on its northern side—including the ‘formerly continuous Epping Forest–Hampstead ridge’ (p. 117, section 4) must also have carried surface water. It seems possible, to say the least, that the waters of Lake Hertford crossed this ridge through a col at a height of some 200 feet above present sea-level.

Whatever may be thought about this possibility, it remains true that Dr. Clayton and Miss Brown have finally disposed of the view that the Lea below Ware originated as a subsequent stream adjusted to the line of a monocline and migrating eastward down-dip. The origins of the various elements of the combined Thames-and-Lea system can be seen to be as diverse as the origins of the combined system of the Severn and Warwickshire Avon.

G. H. DURY
*Department of Geography,
Birkbeck College, W.C.1.*

We are grateful to Dr. Dury for his comments and are pleased to note that he agrees with us on the probable effects of the ponding of the former Thames Valley to form Lake Hertford. While supporting his views that the Lower Lea has both breached the former Epping Forest–Hampstead ridge and deeply dissected the lake deposits north of that ridge, there seems to be little chance of reconstructing the development of this stream. Dr. Dury speculates that an overflow may have occurred here and this is clearly possible, but it seems equally likely that a vigorous stream south of the ridge may have breached the ridge by headward erosion. If the overflow channel hypothesis is adopted it suggests that the present course of the Thames was already established before the main breach occurred, or the Thames itself would have adopted the line of the overflow channel.

The events we described do bear some resemblance to those in the Severn basin, but there the Avon had no clay ridge to breach as the lake deposits lay against the ice in the Severn Valley. However, the Avon and the Lea are alike in their recent origin, and in the fact that in the past they have been regarded as subsequent rivers, a view which must now be abandoned.

JOYCE BROWN

K. CLAYTON

*Geography Department,
London School of Economics.*

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